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Delineating policy mixes: Contrasting top-down and bottom-up approaches to the case of energy-storage policy in California

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ABSTRACT

In the light of pressing societal challenges such as climate change and resource scarcity, scholars are increasingly interested in studying policy mixes in the context of sustainability transitions. However, despite numerous conceptual advances and empirical insights, researchers still lack universal criteria or accepted heuristics for delineating policy mixes in these complex policy spaces. We address this gap by conducting an extensive review of the literature, synthesizing best practices, and developing an analytical framework that provides researchers with two archetypical methodological approaches. The top-down approach builds on the idea that the elements of a policy mix originate from an overarching strategic intent. By contrast, the bottom-up approach starts from the definition of a focal impact domain that is affected by a range of policy instruments. For each approach, we outline a systematic analytical procedure, then implement it to scrutinize how policy affects the emerging technological domain of energy storage in California. We find that each approach has particular advantages that render it useful for certain policy mix analyses. Discussing how researchers may choose between the two approaches or leverage their complementarities, we seek to provide the basis for a consistent research program building on the policy mix framework.

1. Introduction

The concept of policy mixes is rooted in the political sciences, but has recently started to gain popularity among scholars in the field of innovation studies (Flanagan et al., 2011; Kivimaa and Kern, 2016). The reason is that the notion of policy mixes directly aligns with the empirical observation that many real-world policy interventions—especially in the context of sustainability transitions—pursue multiple goals, entail multiple policy measures that are shaped by different governing entities, span different policy fields, and involve multiple levels of public administration (Del Río and Howlett, 2013). Hence, scholars warn against overly simplistic analyses of individual policy instruments, and suggest assessing policy interventions from an integrated perspective that emphasizes the benefits of interdisciplinary research (Flanagan et al., 2011; Howlett et al., 2006). Heeding this call, Rogge and Reichardt (2016) have introduced an extended theoretical framework that may help to shed light on the complex multi-level, multi-agent interactions that are assumed to characterize most real-world policy mixes for governing sustainability transitions (Howlett et al., 2006, pp. 137–138). Rogge and Reichardt (2016) define a policy mix as a combination of policy instruments embraced by an overarching policy strategy. While this perspective allows for the study of a wide range of different policy mixes, it also entails a number of challenges for the process of analyzing them. Most importantly, researchers currently lack guidance on the first step of any empirical policy mix analysis—namely, identifying the relevant elements of the focal policy mix.

Often, researchers must use their own judgment to select the appropriate analytical scope for answering a research question on the policy mix. However, the absence of universal criteria or accepted heuristics may ultimately lead to confusion about how to define and delineate policy mixes in different research settings. This is particularly critical in the context of sustainability transitions, which represent highly complex policy spaces engendered by socially constructed domains, sophisticated actor networks, and a plethora of direct and indirect interactions. The current lack of methodological guidance for studying these phenomena is problematic for several reasons. First, it may lead to overly complex or oversimplified representations of real-world policy mixes, which can undermine the value of the results that arise from such analyses (Flanagan and Uyarra, 2016). Second, it may spur idiosyncratic definitions and delineations of policy mixes, which is especially problematic when tracking policy mixes over time to explore

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their path-dependent nature. Third, it may foster implicitness and inconsistency when it comes to delineating the analytical scope of policy mixes, which could complicate or preclude the comparison of findings across studies, and cast doubt on their external validity. In sum, these issues could undermine the legitimacy of the emerging research stream building on the policy mix research framework, since it is still largely true that "our research tools are not sufficiently advanced for us to make recommendations aimed at improving the nature of instrument mixes and any conclusions reached to date […] must be considered tentative, at best" (Howlett et al., 2006, p. 148).

Therefore, this paper attempts to provide policy mix researchers[1] with actionable, non-prescriptive methodological guidelines for conducting empirical analyses in the context of sustainability transitions. To do so, we build on an extensive review of the growing body of studies that conduct empirical policy mix analyses, and synthesize methodological best practices for delineating the elements of policy mixes (cf. Section 2). By mapping the insights that arise from the literature on to the existing conceptual frameworks outlined above, we derive two archetypical approaches for identifying and delineating policy mixes: top-down and bottom-up. These are introduced in detail in Section 3. To show how these methodological procedures can be applied in practice, we use each one to systematically assess an exemplary policy mix in the context of California's energy transition. Focusing on the emerging technological domain of energy storage, we draw on a comprehensive body of archival data and 24 semi-structured interviews with government officials, industry representatives, and academic experts. The results, presented in Section 4, reveal that both approaches have specific characteristics that make them appropriate for different policy mix analyses. In addition, in Section 5 we discuss the benefits (e.g. comprehensiveness) and downsides (e.g. effort) of combining both approaches, deriving important implications for future policy mix analyses, before Section 6 concludes.

2. Theoretical background

2.1. The challenge of delineating policy mixes in the context of sustainability transitions

Despite recent advances in the concept of policy mixes in the context of innovation and sustainability transitions (Kivimaa and Kern, 2016; Markard et al., 2012; Rogge and Reichardt, 2016), the first step of any policy mix analysis remains a challenge. The problem lies in delineating the relevant elements—i.e. strategies and instruments—of the focal policy mix. While it has been acknowledged that "boundary setting" and "operationalizing the policy mix" have significant implications for the subsequent analytical process and the insights it provides, there seems to be a consensus that no universally appropriate "policy mapping" approach exists. This is in line with Rogge and Reichardt (2016, p. 1630), who point out that the boundaries of the policy mix "can vary substantially" depending on the research question and case. The expansive bandwidth of policy mix analyses can be illustrated with two recent studies. In the first, a consortium of international organizations outlines a policy mix on the global level, making a concerted effort to encompass misalignments across a variety of policy domains (e.g. fiscal, competition, and trade policies), and to systematically list the policy elements that inhibit investment in low-carbon investments around the world (OECD/IEA/ITF/NEA, 2015). In the second, by contrast, Murphy et al. (2012) provide detailed insights into a geographically confined policy mix whose elements drive investments into energy efficiency in private residences in the Netherlands.

While these examples show that the policy mix concept can be applied to a variety of different empirical settings, they also reveal at least three difficulties that researchers face when defining policy mixes in the context of sustainability transitions. First, transitions geared towards pressing societal challenges such as climate change or resource scarcity are characterized by the confluence of fundamental technological, economic, socio-cultural, and institutional change (Markard et al., 2012; Mowery et al., 2010; Shove and Walker, 2007). Accordingly, any transition of a given socio-technical system through "major policy initiatives" must be governed within extremely complex and contested "policy spaces" (Howlett et al., 2006, p. 138; Kergroach et al., 2017, p. 22). Due to the inherent uncertainty and the large number of actor networks involved in system-level transitions, many of the corresponding "domain descriptors" (e.g. "climate policy," "renewable energy policy," "onshore wind policy") are socially constructed, and thus may differ across communities and change over time. In other words, policy mixes often involve fundamental policy reforms whose "re-design and implementation does not take place on a bare slate" (Kern and Howlett, 2009, p. 392). As a result, "different investigators often describe domains differently, arriving at different interpretations of their contours and contents," which may entail "problems of accuracy and replicability, among others", especially when analyzing the aspect of path dependence (Howlett et al., 2006, p. 135; Howlett and Cashore, 2009). Therefore, policy mix researchers should be aware that a significant inductive effort may be required to derive meaningful (i.e. explicit and non-idiosyncratic) definitions of the policy mix, its strategic intent, and the impact domain(s) affected by it. To provide the basis for future policy mix analyses, we define "strategic intent" as a short phrase or label that summarizes the presumed strategic rationale of a given policy mix in a clear and nuanced way.

Second, even if unambiguous domain definitions can be derived, researchers studying policy mixes in the context of sustainability transitions still "[…] have to decide whether it is sufficient to focus on the policy mix creating the protected space for an emerging sustainable technology or whether they also need to pay attention to the policy mix of the encompassing regime, including, for example, subsidies for competing technologies" (Rogge and Reichardt, 2016, p. 1630). While advocating the inclusion of both niche and regime policies, Kivimaa and Kern (2016) stress that the researcher must also use their judgment to decide whether to concentrate solely on the direct effects of policy, or take its indirect impacts into account too. The implications for the analytical scope become clear in their discussion of how low-energy policy mixes affect the innovation system function of resource mobilization: "a policy instrument can directly provide resources (e.g. by setting up a public fund for R&D on energy efficiency) or indirectly stimulate the mobilization of resources by other actors (e.g. by setting vehicle emission standards leading to stronger R&D efforts by car manufacturers […])" (Edquist et al., 1997; Kivimaa and Kern, 2016, p. 215). In sum, policy mix researchers are confronted by a trade-off when it comes to the effort they invest into rendering an inventory of relevant policy mix elements. Incorporating too many, potentially irrelevant elements may lead to an overly complicated, inefficient analysis, and results that are hard to interpret. Conversely, analyzing too few or inappropriate elements corresponds to an omitted variable bias, and may lead to results that are based on an overly simplistic portrayal of real-world policy mixes (Flanagan and Uyarra, 2016).

Third, using inconsistent sets of policy elements to elaborate on similar research questions could complicate or hinder the replicability and comparison of results. This, in turn, could compromise their external validity beyond the specific empirical contexts investigated. Overall, there is a real risk that these issues undermine the scholarly community's intent to develop "policy design theory […] to better inform policy design practice" (Del Río and Howlett, 2013, p. 4).

2.2. Literature review

To study how policy researchers handle the methodological challenges outlined above, we explored 20 recently published empirical

[1] We understand this group as the academic communities who conduct "policy research" or "policy process research" (Weimer and Vining, 2017, p. 30).

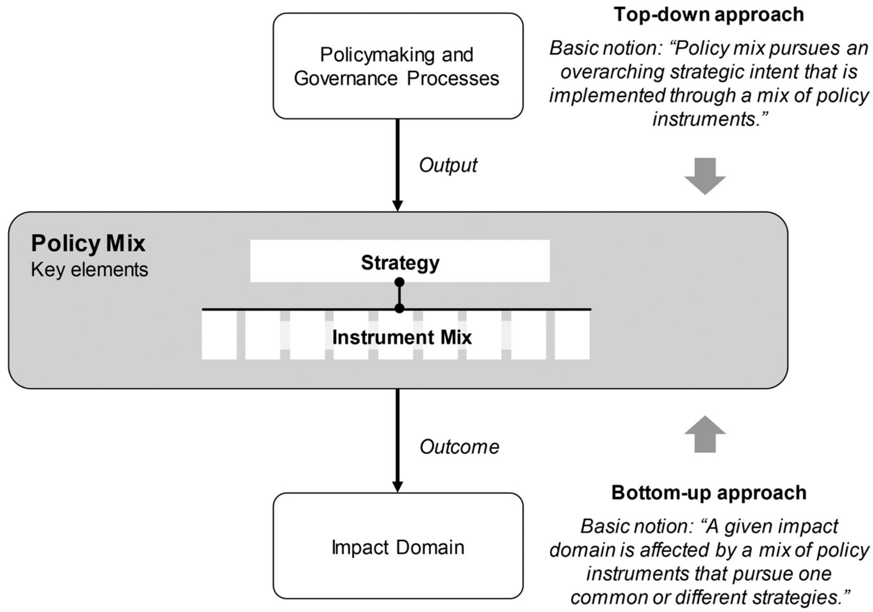

Fig. 1. Two ways to delineate a policy mix: the top-down and the bottom-up approaches. Authors' own illustration based on Rogge and Reichardt (2016, p. 1630), Kivimaa and Kern (2016, p. 210), and Grumm (1975, p. 441).

studies on policy mixes in the context of sustainability transitions. In particular, we screened which methodological approaches the authors used to identify the elements of the investigated policy mix (cf. Table A1 for a comprehensive overview). Our review shows that there are significant differences across the studies in terms of a) their goal or research question; b) their empirical focus; c) the methodology employed; d) the data collected; and, in turn, e) the policy mix elements identified. However, despite these differences, we also find similarities. Scrutinizing the most informative of the aforementioned studies reveals that policy mix researchers usually employ one of three specific approaches to delineate the elements of a policy mix.

The first group of studies (categorized as "Group 1" in Table A1) starts by outlining an overarching strategic intent of the policy mix, such as managing the national water resources of Canada (Howlett et al., 2006). Policies that do not pertain to the policy strategy under investigation are mostly framed as part of the institutional context of the particular research setting. Based on this notion, the authors usually concentrate on one or two specific governance levels (e.g. the federal level) and often further specify the policy strategy in terms of tangible objectives or principal plans. This includes gaining an overview of the governing entities that are in charge of the design, implementation, and governance of the focal policy mix—or, to put it differently, that have "ownership" over its key elements (Quitzow, 2015, p. 237). "Since public agencies are good record-keepers" (Rose, 1988, p. 223), the secondary data provided by the aforementioned entities—e.g. in the form of program handbooks, regulatory proceedings, or legislative texts—allows researchers to build up an extensive overview of the relevant policy instruments. In many cases, this keyword-based or manual archival data analysis is enriched by interviews with government officials; in order to increase the comprehensiveness and accuracy of the repository of policy elements.

By contrast, the second group of studies ("Group 2") starts by sketching a specific domain that is affected by policy in a particular geographic scope, such as distributed solar photovoltaics (PV) in the United States (Proudlove et al., 2016). In most cases, there is no further argument regarding how far the chosen domain can actually be considered "strategic" in the sense of realistically providing a self-standing strategic objective for any policymaker. Based on this notion, researchers usually also define a particular parameter to measure the policy impact (e.g. the economics of a particular technology), and attempt to identify all policy instruments that are considered relevant under this definition. To do so, they draw on archival data or personal interviews to incorporate the expertise of the stakeholders who shape the focal domain (e.g. by developing and marketing new technologies), such as representatives of private firms, industry associations, NGOs, or individual households. Finally, the list of identified policy instruments may be used to uncover the associated governing entities and the corresponding policy strategies, which often comprise multiple governing levels (e.g. federal, municipal) and span policy fields (e.g. climate policy, energy policy, industrial policy). For this reason, the studies concerned often elaborate on the interactions between policies from different fields, policy barriers, and issues associated with policy layering. For example, in their studies on the policy mix for research and development (R&D) and policy impediments to energy efficiency, Nauwelaers et al. (2009) and Sovacool (2009) respectively take both intentional and unintentional policy effects into account.

Finally, the third group of studies ("Group 3") can be regarded a blend of the first two. These studies usually begin by outlining a specific impact domain affected by policy, and use this definition as a basis for the overarching strategic intent of the policy mix—e.g. the policy mix promoting the development and diffusion of offshore wind in Germany (Reichardt et al., 2016). In this respect, this approach acknowledges that the initial definition of the scope of the policy mix is far from unproblematic, since many of the "domain descriptors" are socially constructed, as stated in the previous section. To address this aspect, policy mix researchers have started to combine "several different investigative techniques" (Kern and Howlett, 2009, p. 396). This usually includes screening existing publications on the focal policy domain, collecting and analyzing a comprehensive list of archival data, and conducting a range of interviews with various different actor networks. For example, based on an event study, Reichardt et al. (2016) analyze interdependencies between the German offshore wind-policy mix and the underlying technological innovation system (TIS). Complementing an analysis of secondary data, they gain rich insights into the reoccurring patterns of systemic problems and adjustments of the policy mix via expert interviews with representatives from government agencies, firms, research institutes, and an NGO. While the Group 3 approach is the most comprehensive for delineating the elements of policy mixes, it may become extremely time-consuming and expensive.

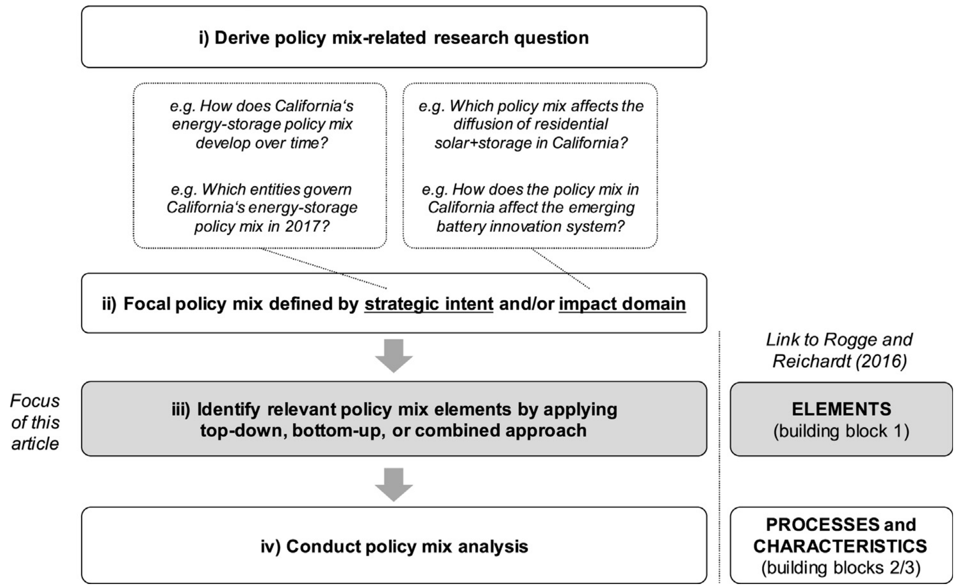

Fig. 2. Analytical framework – from research question to policy mix analysis.

2.3. Two archetypical approaches to defining and delineating policy mixes

Iterating between the literature review, which provides us with rich insights into how policy mixes have been studied empirically, and the research framework on policy mixes provided by Rogge and Reichardt (2016), we conclude that two fundamentally different ways to define and delineate a policy mix can be distinguished.[2] As illustrated in Fig. 1, we term them the "top-down" and "bottom-up" approaches.

The idea behind these labels is that the two approaches operate in opposite directions when identifying the elements of a policy mix. Simply put, the top-down approach picks up the notion that a policy mix is characterized by an overarching strategic intent (such as climate change mitigation) and subsequently reveals the corresponding mix of policy instruments embraced by the focal policy strategy. By contrast, the bottom-up approach starts from a specific domain affected by policy (such as energy efficiency in residential buildings) and identifies the policy instruments that—whether intentionally or otherwise—exert an impact on the focal outcome, while pursuing one common or different policy strategies. In addition, the framework explicates the role of actors, who have only been included rather implicitly in the current research framework on policy mixes. In particular, we suggest framing policymakers and the organizational structure of the key governing agencies as the missing link between policy mix processes and policy mix elements (Rogge and Reichardt, 2016, p. 1629). Moreover, explicitly incorporating the stakeholders who shape the focal impact domain may be a valuable addition when it comes to gaining an in-depth understanding of the bidirectional link between policy mixes and sustainability transitions.

Even though most studies implicitly make the above mentioned distinction, our review has shown that policy mix researchers do not seem to consciously choose between the different approaches. This is surprising in light of the fact that the decision seems to have significant implications for the set of policy mix elements that are identified, and that provide the basis for the subsequent analyses. Overall, we find the methodology sections of many empirical policy mix analyses to be characterized by a remarkably low level of detail in terms of how the focal mix is defined and operationalized. Due to their implicitness, one-quarter of the studies we analyzed could not be unambiguously assigned to any of the three groups outlined above. This situation seems to have attenuated slightly in recent years, which may be related to the convergence of the underlying research framework and a higher proportion of articles on the policy mix concept being peer-reviewed before publication. However, we believe that a much better understanding of the two approaches, both conceptually and in terms of their implementation, is required in order for policy mix researchers to make conscious decisions about which approach is most appropriate for their research design. This could provide the basis for more explicit, systematic, and consistent policy mix analyses.

Therefore, in the following section we suggest how the two approaches introduced above can be integrated into an analytical framework for the study of policy mix-related research questions. In addition, we explain in detail how researchers may use the top-down and bottom-up approaches to delineate the elements of policy mixes in the context of sustainability transitions. Finally, we apply both approaches to identify the elements of two particular policy mixes in the context of California's energy transition.

3. Methodology and data

3.1. Analytical framework

This section outlines how the top-down and bottom-up approaches can be integrated into an overarching analytical framework. Fig. 2 outlines in a stylized fashion how researchers who elaborate on a policy mix-related research question (step i) may proceed to identify the relevant elements of the policy mix under investigation (steps ii and iii), so to say the *content*, before eventually analyzing the *features* of the focal phenomenon (step iv). The procedure directly links to the three building blocks introduced by Rogge and Reichardt (2016)–namely policy mix elements, processes, and characteristics–and is therefore consistent with the corresponding conceptual framework for studying policy mixes.

In line with the insights derived in Section 2, we argue that there is no "magic bullet" for deciding when to apply which approach. Instead, this decision should be made by the policy mix researcher who is best equipped to judge whether the policy mix under investigation is defined by a given strategic intent, or by its effect on a given impact domain (step ii). Once this evaluation is made, the researcher may collect an inventory of the relevant policy mix elements by following the

[2] While a detailed empirical assessment of combining the two approaches goes beyond the scope of this study, we further elaborate on this option in Section 4.3, after having introduced the individual approaches in great detail, and implemented them in an exemplary fashion.

Table 1
How to systematically identify the elements of a policy mix (iterative process).

Step		Top-down approach	Bottom-up approach
Define analytical scope	1	Define *time frame* for the analysis	Define *time frame* for the analysis
	2	Specify the overarching *strategic intent* of the focal policy mix	Select a) metric and b) boundary of the *impact domain*, i.e. define the focal technology(ies), use case(s), business model(s), customer segment(s) and state how they are affected by the focal policy mix
	3	Determine the *vertical* (policy levels) and *horizontal* (geographic scope, policy fields) *dimensions* of the focal policy mix and identify relevant governing entities	Select *geographical scope* of impact domain and identify relevant *actor networks*
Collect and analyze data	4	Identify all features of the *policy strategy* through the objectives of the relevant governing entities, based on secondary data	Identify all relevant *policy instruments* across governing entities and levels (horizontal and vertical dimensions); enrich secondary data with interviews
	5	Identify all relevant *policy instruments* of the focal policy mix by drawing on the sources revealed before; enrich secondary data with interviews	Identify *policy strategy(ies)* behind corresponding instruments; based on secondary data
	6	*Illustrate policy mix elements*	

methodology outlined below. Table 1 summarizes in a simplified fashion how the elements of policy mixes can be identified using the top-down and bottom-up approach. The six-step procedure is not to be seen as a rigid sequence, but rather as an iterative process that allows researchers to move back and forth between the individual steps until empirical saturation is reached—i.e. the inventory of policy mix elements is considered sufficiently comprehensive. In sum, both approaches rest on the combination of a deductive content analysis based on secondary data and inductive case-study research based on interviews with representatives from different actor networks (Flick, 2009; Yin, 2009). This renders both approaches suitable for a variety of different research designs, and may allow researchers to explore a variety of policy mix aspects that have been under-theorized so far (Eisenhardt and Graebner, 2007). Examples include the underlying policy making and implementation processes, interactions between the elements, as well as the four archetypical characteristics (consistency, coherence, credibility, comprehensiveness) of policy mixes as outlined by Rogge and Reichardt (2016). However, there are also a number of differences between the two approaches that we now explicate, as they may provide guidelines for future policy mix analyses in different empirical settings.

For example, whereas the top-down approach has a deductive vantage point, the bottom-up approach starts from a more inductive basis. The reason is that the top-down approach is based on the definition of a strategic intent, which may be used to refer to existing maps of the policy mix, such as the Overview of Legislation Governing Germany's Energy Supply System (BMWi, 2016). Alternatively, it may provide the basis for developing a keyword-based filter and applying it to publicly available policy repositories, such as the Global Renewable Energy Policy and Measures Database (IEA/IRENA, 2017) or the Science, Technology and Innovation Policies Database (EC/OECD, 2016; Kergroach et al., 2017). Thereby, the top-down approach allows researchers to conveniently derive a fairly comprehensive overview of potentially relevant policy mix elements and very quickly arrive at an initial estimate for the data-collection effort. In this respect, the approach resembles the "program approach" and the "legislative approach" introduced by (Rose, 1988) and (Hosseus and Pal, 1997) respectively, which "rely on the association of government agencies and programs to define a policy domain" and which may "result in an easily obtained, inexpensive, and accurate, representation of activity within a domain" (Howlett et al., 2006, p. 135).

More often than not, however, "the specification of design features [of policy mix elements] will not be as straightforward but require further analysis, as these cannot always be directly derived from publicly available documents and data bases" (Rogge and Reichardt, 2016, p. 1631). Therefore, it may be necessary to consult with representatives of the corresponding governing entities to gain further insights and fill in the missing data entries. In addition, policy mix researchers should be aware that many of the domain descriptors are socially constructed (cf. Section 2.1), and hence ensure that the focal strategic intent is also used officially by the actors in charge of governing it—e.g. the federal government, or a specific ministry. Since this is often hard or impossible to say with certainty when analyzing nascent policy mixes, the researcher may have to introduce a novel domain descriptor as part of the focal research project, while taking care not to be overly idiosyncratic.

By contrast, the bottom-up approach starts from a more inductive approach. Therefore, the initial definition of an impact domain may well be idiosyncratic, as long as it is properly defined, transparently introduced, and aligned with the focus of the research project. Once defined, the impact domain serves as a lens for capturing a broad spectrum of policy mix outcomes from different governance levels, entities, and policy fields. In other words, with the bottom-up approach, researchers do not need to decide initially[3] which entities to include or exclude; the insight emerges from the data-collection process. Therefore, this technique is particularly useful for exploring policy mixes whose boundaries are hard to delineate—e.g. when many different governing entities are involved, as is often the case in the context of sustainability transitions. To substantiate the effect of policy on the focal impact domain, the bottom-up approach draws on information provided by the actors who shape it—e.g. firms and individuals driving innovation in a particular sector. The reason for this is that even if the entities responsible for governing policy mixes do build up strong regulatory capacity, in the case of complex policy spaces (cf. Section 2.1), the aforementioned actor networks are usually closest to their specific impact domain and have a vested interest in knowing its characteristics and drivers better than anyone—including the intended and unintended effects of policies, transcending the boundaries between policy fields, levels, or mixes. As Kivimaa and Kern (2016, p. 215) state, "interviews with target group actors could shed light on how actors interpret the signals they receive from different policy instruments." Nonetheless, collecting these insights often involves a significant research effort to collect the corresponding archival data and enrich it by conducting personal interviews with the aforementioned stakeholders. Hence, the narrower the definition of the focal impact domain, the easier it is to implement the bottom-up approach. For example, when elaborating on the impact of policy on technological innovation, it may make sense to choose a specific technology or sub-technology (e.g. onshore wind power), rather than looking at an entire technology domain (e.g. renewables). When studying multi-purpose or general-purpose technologies, it may also be worth specifying the applications in which the focal technology may be used (Arthur, 1989; Huenteler et al., 2016a, 2016b; Malhotra et al., 2016; Schmidt et al., 2016).

[3] By contrast, following the top-down approach the researcher determines the horizontal and vertical dimensions of the policy mix initially, either herself or based on the information provided by existing policy repositories. For example, focusing on the state level means abstracting from additional policy elements that are governed on the federal or the municipal level.

Since the top-down and bottom-up approaches are so different, it could be argued that only using them in combination reveals the most accurate and comprehensive inventories of policy mix elements. Even though a detailed empirical assessment of combining the two approaches goes beyond the scope of this study, we further elaborate on this option in Section 4.3, after having implemented the individual approaches in an exemplary fashion.

3.2. Research case: California's energy transition and the emerging domain of energy storage

In the following, we elaborate on a research case that shows how the top-down and bottom-up procedure can be implemented in practice to identify the elements of policy mixes in the context of sustainability transitions. As stated in Section 2.1, sustainability transitions are engendered by fundamental socio-technical change. A prominent example is the transition of the energy sector, which is regarded as pivotal for effective climate-change mitigation (Hood (IEA) and Briner (OECD), 2014; IPCC, 2014). In particular, the Intergovernmental Panel on Climate Change (IPCC) has shown that the two essential supply-side mitigation measures are an increase in the share of low-carbon electricity supply from the current 30% to about 80% in 2050, and a phase-out of fossil fuels by 2100. However, implementing this "energy transition" requires overcoming a series of "technological, economic, social, [and] institutional challenges."[4] (IPCC, 2014, p. 20) In a comprehensive effort to reduce greenhouse gas emissions in the energy, transportation, and building sectors, the state of California has introduced an unprecedented policy reform with ambitious decarbonization milestones leading up to 2050 (Fouquet, 2008; Gallagher et al., 2012; IPCC, 2014, p. 20; Nill and Kemp, 2009). As part of this reform, the state supports the deployment of renewable energy technologies such as wind power and solar photovoltaic through different policy measures, e.g. procurement goals and subsidies. Due to the increasing penetration of intermittent renewable resources, the state has also started to spur the development and market uptake of complementary technologies such as energy storage. This is a technological domain that has become more of a strategic priority for realizing the state's energy transition in recent years, as reflected e.g. in a dedicated state-level roadmap (CAISO/CPUC/CEC, 2014a, 2014b).

However, despite some consolidation efforts by the leading state government agencies in the energy sector, there is currently no database or report that offers a comprehensive overview of policies relevant for the energy-storage domain in California, let alone the interaction or interdependencies between these policies. Due to the confluence of different policy fields and the complex interactions between arrays of policy instruments, the empirical setting outlined above provides an ideal research case for exploring different ways to operationalize a policy mix. To do so, we start from two exemplary policy mix definitions and explain in detail how we proceeded to identify their elements based on the top-down and bottom-up approaches, following the procedure outlined in Table 1.

3.3. Using the top-down approach to identify the elements of California's energy-storage policy mix

3.3.1. Time frame

Since energy storage has only recently[5] become a strategic priority for policymakers on the state level, we set a rough time frame of 2000–2016 for the policy mix elements we would like to identify.

3.3.2. Strategic intent

We follow the top-down approach to delineate California's energy-storage policy mix. More precisely, the purpose is to render a comprehensive overview of the policy strategies and instruments that further the goal of fostering technological innovation in the field of energy storage.

3.3.3. Vertical and horizontal dimensions

We confine our analysis to the state of California. Based on this empirical scope we proceed to unpack the governance structure behind the policy mix. As a first step, we screen two extant analyses on California's renewable-energy instrument mix[6] in order to understand how the state has governed its energy transition in the past (Carl et al., 2012; Shmidt et al., 2012). This includes gaining an overview of the central governing entities (their history, mission, and organizational structure) and the relationships among them (vertical and horizontal coordination; individual and joint initiatives). We find that the political agenda in terms of the policy strategy is jointly shaped by the Governor's Office and the Legislature, i.e. the Assembly and the Senate. Four state-level entities are jointly responsible for the design, implementation, and administration of the emerging storage-specific instrument mix, given their expertise on different aspects of the energy sector and distinct authorities over them. They are the California Public Utilities Commission (CPUC), the California Energy Commission (CEC), the California Independent System Operator (CAISO), and the California Air Resources Board (CARB).[7]

3.3.4. Policy strategy

Drawing on publicly available data (e.g. original bill drafts, or ancillary publications such as annual reports) retrieved from the websites of California's executive and legal branch, we manually collect a comprehensive database of all the strategy elements in effect in 2016, including guiding legislation, directives, targets, and principal plans. This includes: their commonly used acronym; their type; a brief description of their mechanism; the entity or entities responsible for their governance; and the year they came into effect (cf. Table A4).

3.3.5. Policy instruments

In addition to publicly available data (e.g. original documents of regulatory proceedings or dedicated program websites) retrieved from the four governing entities, we manually collect a comprehensive database of all the policy instruments in effect in 2016, such as R&D support, procurement schemes, or regulatory standards. This includes their commonly used acronym, their type, a brief description of their mechanism, the entity or entities responsible for their governance, and the year they came into effect (cf. Table A4). Additional data from two policy databases—namely the Database of State Initiatives for Renewable Energy (DSIRE, 2016) and AEE Powersuite (AEE, 2016)—comprising reports by research institutes, press articles, stakeholder workshops, and webinars, allows us to fill in the missing entries in our database and thereby complete the extensive[8] process of archival data collection and analysis. In order to challenge the comprehensiveness of

[4] "Examples of these four issues are i) physical infrastructures designed around fossil fuels […] (Arthur, 1989; Markard, 2011), ii) unpriced externalities that distort competition (Gallagher et al., 2011), iii) lack of acceptance of novel technologies (Negro et al., 2012), and iv) legal and regulatory structures that favor incumbent players deeply embedded into the predominant 'techno-institutional complex' (Unruh, 2000)" (Jan Ossenbrink, 2017).

[5] The report *Advancing and maximizing the value of Energy Storage Technology – A California Roadmap* was published in December 2014, culminating "years of work and input from more than 400 interested parties" (CAISO/CPUC/CEC, 2014a, Foreword).

[6] The authors coined the terms "renewable jungle" and "regulatory maze" to express the complexity and effort required to understand how California's energy transition is governed.

[7] While CAISO is a federal agency located in California, the other three bodies (CPUC, CEC, and CARB) are state entities.

[8] The fact that there are currently more than 300 open regulatory procedures (so-called "dockets") on the topic of "energy storage" in California (AEE, 2016) shows that California's energy-storage policy mix is very much in flux, and emphasizes the challenge of gaining an overview of the most important developments.

our data repository, we consult a number of policymakers and regulators, as well as industry experts active in the domain of energy storage in California, with a summary of our database. In sum, for the top-down approach we conduct 15 semi-structured interviews (eight with policy makers, seven with experts[9]) between March and November 2016. Each of the interviews is followed by a careful review of our database and a decision on whether to add or remove any elements.

3.3.6. Illustration

Once empirical saturation is reached—i.e. no additional elements are mentioned and none of the elements are identified as obsolete—we render a visual overview of the policy mix, following best practices from the literature (cf. Section 2.2).

3.4. Using the bottom-up approach to identify the policy mix affecting the economics of energy storage for residential PV self-consumption in California

3.4.1. Time frame

The bottom-up approach is intended to reveal the policy mix elements relevant to the focal stakeholders (cf. below) in 2016, and all relevant policies active in this year are taken into account, irrespective of when and how they came into effect.

3.4.2. Impact domain

We follow the bottom-up approach to delineate the elements of the policy mix that directly affect the economics of three stationary energy-storage technologies for residential rooftop PV self-consumption in California, namely lithium-ion battery storage, air-sourced heat pumps, and immersion heaters. These distributed energy storage (DES) technologies have been chosen since their characteristics differ greatly, but their use case is likely to gain relevance in light of California's emerging residential solar PV market and the near-term phase-out of support schemes for standalone systems. In a parallel to events occurring in Germany or Australia, these developments could spur the demand for DES, which provides a promising solution to accommodate high shares of customer-sited renewable energy installations and, hence, could become an enabling technology for the energy transition (Fitzgerald et al., 2015; Von Appen et al., 2015). However, the different technologies may address state-level policy goals to a different extent (details provided in Table A5). The focal impact metric[10] *Economics* has been selected, as it represents a common indicator in market analyses used by the industry, and because the bottom-up approach provided the basis for a subsequent techno-economic study conducted by the authors. Finally, we exclude policies that affect the abovementioned impact domain only indirectly.[11]

3.4.3. Geographical scope and actors

The key stakeholders in this domain are individual homeowners in California and the firms offering the corresponding energy-storage systems. As part of this analysis we focus on the latter, namely solar + storage vendors, and in particular their senior policy managers.[12] This is based on the assumption that they are best informed about the wide range of policies that affect the economics of solar + storage systems, given the direct implications for their product offerings, business model, and ultimately firm performance. In addition, we expect that the dominant firms in this ecosystem are equally well informed about the relevant policies, which provides a convenient basis to triangulate between them, instead of having to interview a large group of individuals to account for heterogeneity in their level of expertise about their policy exposure.

3.4.4. Policy instruments

To identify the instruments of the policy mix specified above, we start by screening the websites of the firms active in the focal impact domain to assess how exposed their product offerings are to policies. In particular, based on the experience of the research team in terms of similar technologies and markets, we build a stylized investment model that includes all the relevant cash flows of a solar + storage system. Incorporating insights from the academic literature as well as a set of industry reports (Darghouth et al., 2011; Hoppmann et al., 2014; Luthander et al., 2015; Sivaraman and Moore, 2012), we develop a set of hypotheses about the likely effect of different policy instruments on the cost and revenues of solar + storage systems in California. This list of instruments is subsequently cross-checked and further substantiated in an initial round of interviews. To do so, in addition to reaching out to the two most relevant industry associations, and a leading electric utility company active in California, we ask the representatives of four of the largest vendors of residential solar + storage systems whether or not the profitability of their offerings is affected by the policy instruments we had previously identified, and whether any relevant elements are missing. This process is iterative and involves going back and forth between the primary and secondary data. Analogously to the top-down approach, for each policy instrument we manually gather data on the corresponding policy type, its mechanism, and potential interactions with other instruments (cf. Table A6), using a similar range of data sources comprising e.g. reports from industry associations, press articles, and webinars.

3.4.5. Policy strategy

Because it has less of a direct effect (or no effect) on their respective activities, the strategic rationale that the identified policy instruments pursue is of only limited interest to the majority of the stakeholders in the investigated domain, and hence our interview partners. Therefore, the relevant policy strategies are identified through desk research. We assume that each policy instrument is nested in (and can therefore be at least loosely associated to) a policy strategy, such as a guiding piece of legislation or the mission statement of the corresponding government entity. Thus we first find out which entities are involved in governing the focal instrument mix. In the process, we identify agencies from three policy levels—federal, state, and local—and, drawing on their online data repositories as well as comprehensive additional archival data, we are able to subsequently augment our database with the relevant strategy elements. To refine and conclude our data collection, we conduct a second round of interviews with the aforementioned companies and industry experts in California. In sum, for the bottom-up approach we conduct 16 semi-structured interviews (nine with industry representatives, seven with experts[13]) between March and November 2016. Each of the interviews is followed by a careful review of our database of policy mix elements and a decision on whether to add or remove any elements.

3.4.6. Illustration

The visual overview of the policy mix derived through the bottom-up approach unfolds along similar principles as the top-down approach, following best practices from the literature, except for the fact that it additionally emphasizes the different policy levels (i.e. federal, state, and local) included in the analysis.

[9] The panel of experts helped us refine the inventories of policy mix elements we collected to implement both the top-down and the bottom-up approach.

[10] Alternative metrics include *Patents* (to proxy knowledge creation); *Public acceptance* (survey data); or *Diffusion* (market data)

[11] When comparing the top-down and bottom-up approaches, we realized that there are several "indirect"—i.e. non-financial—policy effects, e.g. regulatory procedures for connecting the focal energy storage devices with the grid, or providing information on energy efficiency to households. For illustration purposes, we decided not to incorporate these effects into the focal impact domain.

[12] In the words of one of our interviewees, we were looking for "people who can bridge the gap and combine the expertise on the technology and business models with an understanding of the policy side."

[13] The panel of experts helped us refine the inventories of policy mix elements we collected to implement both the top-down and the bottom-up approach.

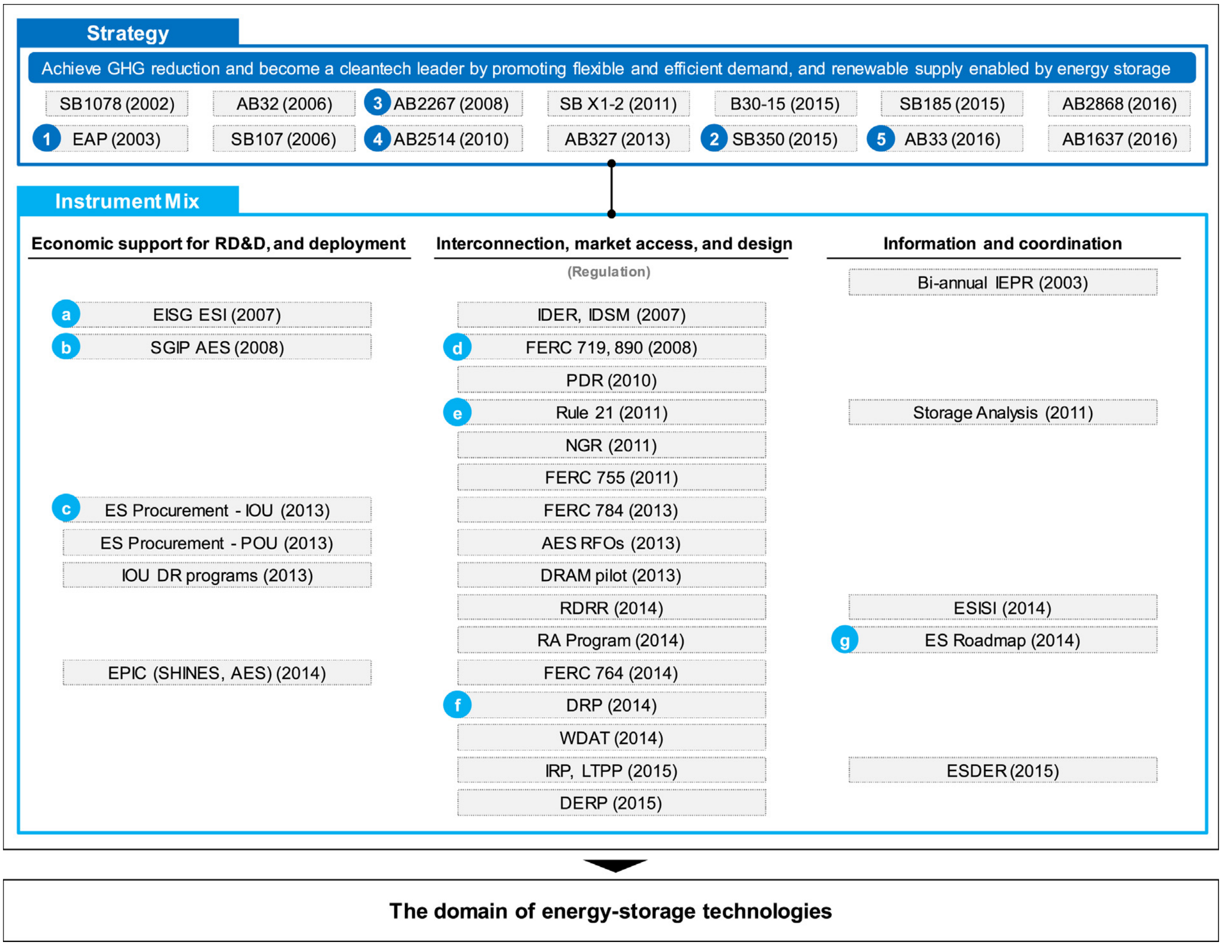

Fig. 3. Outcome of the top-down approach – California's energy storage policy mix in 2016; policy instruments are listed according to the year they came into effect (vertical axis) and categorized by type (horizontal axis); all abbreviations and features of the corresponding policy elements are detailed in Table A3.

3.5. Data

Both the top-down and bottom-up approaches draw on two main sources of data: a comprehensive set of secondary data collected via desk research (cf. Table A2), and interview data gathered in a total of 24 semi-structured interview sessions (cf. Table A3). With respect to the archival data, for the top-down approach we mainly draw on data from government websites and interviews with representatives of government agencies and experts on California's energy sector (cf. Table A3, groups I and III). For the bottom-up approach, we use data from industry associations, firm websites, and interviews with industry representatives, as well as experts on California's energy sector (cf. Table A3, groups II and III).

As outlined in Table A2, the secondary data can be clustered into three categories: data on policy strategies, data on policy instruments, and ancillary documents. As outlined in Table A3, the interviews can be clustered according to the three groups of interviewees: policymakers and analysts; representatives of the energy-storage industry; and experts from leading academic institutions on the energy transition in California and the U. S. Each interview was conducted in person or over the phone and lasted between 15 and 75 min. For about half of the discussions, we arranged dedicated interview sessions, while the other half took place during breakout sessions in four academic[14] and two practitioner conferences.[15] We granted the interviewees anonymity to facilitate an open conversation. As a result, the quotes used in this article are not attributed to individual interviewees, but rather to the category each interviewee belongs to.

4. Results

In this section we present an overview of the two policy mixes derived by the exemplary implementation of the top-down and bottom-up approaches outlined in Sections 3.3 and 3.4 respectively. Comparing the elements of the two "test inventories" (Howlett et al., 2006, p. 146), we subsequently discuss the degree to which researchers may leverage complementarities between the two approaches.

4.1. Outcome of the top-down approach: California's energy-storage policy mix

According to the top-down approach, California's energy-storage policy mix consists of a strategy comprising 14 elements, and an

[14] The academic conferences were: Power Conference at Haas, UC Berkeley (2016); *(footnote continued)* Silicon Valley Energy Summit (2016) at Stanford University; Utilities Workshop at Stanford Graduate School of Business (2016); and Modernizing the Grid Workshop by the U.S. Department of Energy at Stanford University (2016).

[15] The two practitioner conferences were: Energy Storage Europe Conference (2015) and California's Distributed Energy Future Conference (2016).

instrument mix comprising 27 elements (details provided in Table A4). Fig. 3 provides an overview of these elements, highlighting particular parts of the strategy (1–5) and the instrument mix (a–g) detailed below. In the following, we first introduce the strategic elements of California's energy-storage policy mix, and subsequently present the mix of policy instruments.

The strategy behind California's energy-storage policy mix is nested in the state's overarching climate-change and energy-transition strategy, which was initiated by the Legislature as a response to an energy crisis in the early 2000 s that spurred the development of the Energy Action Plan (EAP)[16] (cf. Fig. 3-1). Over time, this strategy was complemented by milestones for greenhouse gas (GHG) reduction, energy efficiency, and renewable procurement that were regularly extrapolated and intensified, most recently through Senate Bill 350 in 2015 (cf. Fig. 3-2). The energy-storage domain appeared on the policy agenda in the late 2000s, when studies by leading research institutes projected an increasing demand for fast-ramping capacity[17] due to the significant increase in intermittent, renewable generation. Energy storage and demand response were discussed as the two main alternatives to building new gas-fired peaker[18] plants. After a significant period of discussion, policymakers recognized the need for substantial and timely cost decreases for energy-storage systems, and eventually decided to support the formation of an energy storage niche market to enable industry growth and spur scale and learning effects. Moreover, in 2008 Assembly Bill 2267 (Fig. 3-3) increased the upfront grants available to distributed energy-storage systems by 20% in case the technology was sourced from a supplier located in California. This indicates that industry policy—i.e. the creation of an energy storage lead market—was a central part of the strategic considerations behind California's energy-storage policy mix.

However, it was not until California initiated a dedicated storage procurement mandate to be achieved by the large state-regulated utility companies that the state's energy market and industry really gained traction. In particular, Assembly Bill 2514 (cf. Fig. 3-4) directed the CPUC to "open a proceeding to determine appropriate targets […] for each load-serving entity to procure viable and cost-effective energy storage systems" (AB2514, 2010, p. 2). In the words of one of our expert interviewees, this policy was "a great first step for the entire industry [since] it led to a complete change in the mindset about storage." The legislation was recently complemented by Assembly Bill 33, which focuses on long-duration energy storage[19] (cf. Fig. 3-5).

As indicated above, the strategic objectives and principal plans introduced by California's executive and legislative branch set in motion a series of activities by the state's four major agencies responsible for governing the electricity sector. As illustrated by the three columns in the lower part of Fig. 3, we find that the mix comprises three types[20] of policy instruments: economic support, regulation, and information. This suggests that California's policymakers pursue a multi-lateral approach when it comes to establishing energy storage systems as a novel technology domain in the electricity system. The fact that most of the instruments have been implemented over the last five years underscores the dynamics behind California's emerging energy-storage policy mix, and the importance that legislators and regulators assign to it. Fig. 4 provides an overview of CPUC, CAISO, CEC, and CARB as the central entities responsible for the design, implementation, and administration of the emerging storage-specific instrument mix, due to their expertise on, and authorities over, different aspects of California's energy sector.

Since California's electricity system faced the challenge of introducing new power plants while gradually replacing a fleet of existing ones in the late 2000s, policymakers deemed technological advances in the energy-storage domain worth exploring, and subsequently put a number of economic instruments in place (cf. Fig. 3, left-hand column). In particular, early-stage storage technologies received support from public funds for research, development, and demonstration (RD&D), such as the Energy Innovators Small Grant (EISG), which entailed a dedicated subject area for Energy Systems Integration (cf. Fig. 3a). To bridge the gap between innovation and market diffusion in the field of energy storage, in 2008 the CPUC amended the existing Self-Generation Incentive Program (SGIP) and reallocated a proportion of its budget to eligible Advanced Energy Storage (AES) systems (cf. Fig. 3b). However, numerous further amendments to the SGIP were necessary (cf. Fig. A1) before the instrument finally became capable of effectively spurring demand for battery-storage systems—a growing market supported with $83 million in 2016. In addition to these direct incentives, in 2013 California's three state-regulated, investor-owned utilities (IOUs) revealed their plans to procure 1325 MW of grid-connected energy storage through competitive solicitations until 2020 (cf. Fig. 3c)[21] to comply with aforementioned AB2514.

With respect to the state's regulatory complex (cf. Fig. 3, center column), California launched a series of activities to amend the rules for interconnection and market participation of energy-storage devices. Examples include orders 719 and 890 by the Federal Energy Regulatory Commission (FERC) in 2008 (cf. Fig. 3d), which stipulate that Independent System Operators (ISOs), such as CAISO, should not discriminate against new resources. These include energy-storage systems[22] seeking to participate in regional ancillary services markets. In addition, the CPUC has launched a number of proceedings, e.g. adapting the rules and regulations for distribution-level interconnection (cf. Electric Tariff Rule 21) in order to account for the role of electric storage resources (cf. Fig. 3e). Since much of the information on California's electricity system had been in the hands of the three incumbent IOUs, in 2014 the CPUC mandated that the IOUs submit Distributed Resource Plans (DRPs) by mid-2015. The DRP rulemaking[23] can be seen as a prerequisite for turning California's distribution grid into a plug-and-play system, e.g. for distributed energy storage facilities attached to customer-sited renewable energy systems.

Finally, with respect to information and coordination policies (cf. Fig. 3, right-hand column), several reports have been launched in order to facilitate coordination among the different agencies and stakeholders that are driving California's energy transition. For instance, building on the expertise and feedback of more than 400 interested parties, CAISO, CPUC, and CEC developed the Energy Storage Roadmap (CAISO/CPUC/CEC, 2014a) (cf. Fig. 3g). This inter-agency guideline clarifies the milestones and priorities for the state's energy-storage policy mix, and lays out individual and shared deliverables for each of the governing

[16] The EAP involved a "Loading Order," which listed the state's energy policy and investment priorities as based on energy efficiency and demand response, followed by renewable and distributed generation, and by clean fossil-fueled sources and infrastructure improvements.

[17] This scenario—i.e. an increasing trough in California's aggregated load-curve around midday—is currently discussed under the term "duck curve" (Blunden, 2015; CAISO, 2016).

[18] Peaker plants are power plants whose main purpose is to quickly provide additional capacity during peak load hours.

[19] In particular, AB33 highlights the ability of "long duration bulk energy storage resources […] to meet [the] electrical grid's need for rapid ramping capability and the capacity to utilize overgeneration from renewable energy resources" (AB33, 2016, p. 1), asking the CPUC and the CEC to assess the technical potential and carry out cost-benefit analyses for a wide range of storage technologies.

[20] Building on the observation that "the government may either force us, pay us or have us pay, or persuade us," the original article introduced the distinction between "carrots" (economic instruments), "sticks" (regulatory instruments), and "sermons" (provision of targeted information) (Vedung et al., 1998, p. 30).

[21] This figure was increased by an additional 500 MW in 2016 (cf. AB2868).

[22] This passage was later extended to account for the distinct characteristics that battery-storage systems might provide to the electricity system, such as fast-responding and highly accurate frequency regulation (cf. FERC755, 784).

[23] The DRP rulemaking (R.14-08-013), implemented in response to Assembly Bill 327 that passed the year before (cf. Fig. 3-f), requires the utilities to biannually disclose how they intend to integrate distributed energy resources (DER) into their grid planning and operations, by conducting an "Integrated Capacity Analysis" and a "Locational Net Benefit Analysis" and providing public access to the underlying data.

Entities responsible for shaping Policy Strategy

Governor	Assembly	Senate

Entities responsible for shaping Instrument Mix (Instrument Design, Implementation, and Administration)

California Public Utilities Commission (CPUC)	California Independent System Operator (CAISO)	California Energy Commission (CEC)	California Air Resources Board (CARB)
Established 1911	**Established** 1997	**Established** 1973	**Established** 1967
Mission "Provision of *safe, reliable utility service and infrastructure at reasonable rates*, with a commitment to environmental enhancement and a healthy California economy."	**Mission** "Provides open and non-discriminatory *access to the bulk of the state's wholesale transmission grid*, supported by a competitive *energy market* and comprehensive *infrastructure planning* effort."	**Mission** "Reducing energy *costs and environmental impacts* of energy use − such as greenhouse gas emissions − while ensuring a *safe, resilient, and reliable supply* of energy."	**Mission** "Promote and protect public health, welfare and ecological resources through the *effective and efficient reduction of air pollutants* while recognizing and considering the effects on the economy of the state."
Governance "Five Commissioners, appointed by the Governor, approved by the Senate."	**Governance** "Governed by a 5 member board, appointed by Governor, confirmed by Senate." (Though created by the state, not a state-level governmental entity and not subject to regulation or oversight by any state entity but the Federal Energy Regulatory Commission (FERC); complies with NERC; part of Western Electricity Coordinating Council, WECC))	**Governance** "Board made up of 5 Commissioners appointed by the Governor and confirmed by the Senate. The Governor also designates a Chair and Vice Chair as primary agency leads."	**Governance** "Consists of 14 members. 12 are appointed by, and serve 'at the pleasure' of the Governor along with the consent of the Senate. Two additional members are appointed by the Legislature, one by the Senate, the other by the Assembly."
Role for energy-storage policy "Regulates and hence directly orders investor-owned utilities (IOUs), energy service providers (ESPs), and community choice aggregators (CCAs); key agency in charge of implementing California's new electricity infrastructure; sets or influences most of the clean energy policies for the state and funds most of the electric sector programs."	**Role for energy-storage policy** "Sets rules and approves interconnection of generation and storage to the CAISO-controlled grid."	**Role for energy-storage policy** "Primary energy policy and planning agency; prepares the Integrated Energy Policy Report (IEPR) and collaborates with state and federal agencies, utilities, and other stakeholders to develop and implement state energy policies."	**Role for energy-storage policy** "Has become a major force in California's energy efforts besides dealing with local air pollution."
Staff ~1,000 **Budget** $136M (2015)	**Staff** ~1,000 **Budget** $195M (2017)	**Staff** ~1,000 **Budget** $387M (2012)	**Staff** 1,365 **Budget** $582M (2015)

Fig. 4. Overview of relevant entities governing California's energy-storage policy mix in 2016.

entities. In confluence with agency-specific information and stakeholder integration efforts, such as CAISO's Energy Storage Interconnection Stakeholder Initiative (ESISI) or the CEC's biannual Integrated Energy Policy Report (IEPR), these activities complement the mix of instruments that, together with the abovementioned strategies, constitutes California's energy-storage policy mix.

4.2. Outcome of the bottom-up approach: the policy mix affecting the economics of energy storage for residential PV self-consumption in California

We now turn to the policy mix that is specifically defined by its impact on the economics of energy storage for residential PV self-consumption. According to the bottom-up approach, the policy mix consists of an instrument mix comprising 11 elements that are nested in six different policy strategies. The latter are governed on different policy levels[24] and comprise a total of 14 elements (details provided in Table A6). Fig. 5 provides an overview of these elements, highlighting particular elements of the instrument mix (A–G), and strategies (I–III). Since the bottom-up approach identifies the instrument mixes prior to the corresponding strategies, the following section is structured accordingly.

Two of the identified policy instruments are governed on the federal level (cf. Fig. 5A), which represent tax credits to encourage investment into residential solar PV, battery-storage, and heat-pump systems. The instruments are governed by the U.S. Internal Revenue Service (IRS), but rather than acting as fiscal policy instruments in the classical sense, they have been implemented in response to three overarching strategic policy frameworks introduced by the Legislature under the Bush and Obama administrations: the Energy Policy Act (EPACT) of 2005, the

[24] Since these six "strategy/instrument mix" combinations can be regarded as policy

(footnote continued)
mixes in their own right, it might make sense to frame the outcome of the bottom-up approach as a "meta-level" policy mix. Since it is unclear whether this finding holds true in other empirical contexts, we refrain from using this term in the subsequent part of the analysis, and instead continue to use the term "policy mix."

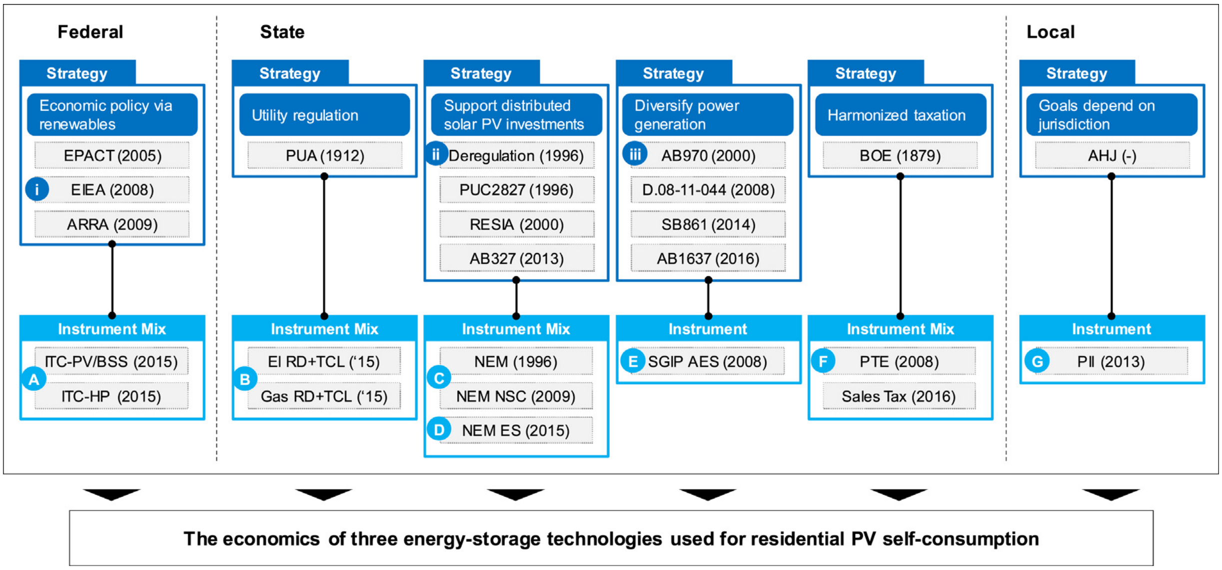

Fig. 5. Results of the bottom-up approach: policy mix affecting the economics of energy storage for residential PV self-consumption in 2016; the numbers and letters indicate policy elements that are detailed in the text; all abbreviations and features of the corresponding policy elements are detailed in Table A4.

Energy Improvement and Extension Act (EIEA) of 2008, and the American Recovery and Reinvestment Act (ARRA) of 2009 (cf. Fig. 5i).[25]

Besides the federal level, there are multiple state-level policy instruments affecting the economics of residential solar PV self-consumption, which can be clustered into four individual instrument mixes. The first group (cf. Fig. 5B) comprises electricity and gas rates set by the regulatory authorities, as well as the corresponding taxes, charges, and levies associated with their consumption. Electricity and gas rate design can be regarded as policy instruments, since California's retail markets for the two commodities are regulated by the state.[26] They are part of the bottom-up policy mix as they affect the economics of energy-storage installations, based on the electricity bill savings that accrue to investors in residential solar + storage systems. The second group comprises California's Net Energy Metering scheme (NEM, cf. Fig. 5C), which mandates utilities to provide bill credits to residential solar PV owners for excess electricity being fed into the public grid. Under NEM, which was introduced in the late 1990s (cf. Fig. 5ii), feeding PV electricity into the grid is compensated at the going electricity retail rate, which renders the investment into solar PV systems economically attractive for an increasing number of residential customers. This policy has been included in our analysis since it determines the revenues that arise from exporting electricity to the grid, rather than storing it onsite for later use. Furthermore, the instrument exempts eligible residential customers from a number of administrative charges and grid interconnection fees. The third group is an individual policy instrument, namely the above mentioned SGIP (cf. Fig. 5E). According to one of the industry representatives interviewed it was "the number one policy instrument that brought distributed energy storage, especially battery storage and therefore [our company], to California". Providing upfront grants and performance-based incentives for stationary battery-storage systems, SGIP has a crucial impact not only on the economics of residential storage systems in general, but also in terms of sizing the individual storage projects, since "part of the optimization is optimizing for the incentive," as a storage-vendor interviewee put it. Looking at the strategy behind SGIP, we find that it can be traced back to Assembly Bill 970 (cf. Fig. 5iii) from 2000, and the original intent to diversify California's power-generation resources.

Even though two of the instruments outlined above, namely NEM and SGIP, are both governed by the CPUC, they fundamentally differ regarding their impact on the economics of battery-storage systems. Whereas SGIP provides financial support for batteries, a policymaker we interviewed told us that, "NEM kills storage by providing the grid as a free battery." Interestingly, this insight was brought to the CPUC's attention based on "a hearing with representatives from the [battery-storage] industry." For a long time, this unintended side effect was overlooked due to the nascent nature of the energy-storage market, as well as the fragmented governance of specific parts of California's energy transition policy mix. In the words of one of our interviewees, "NEM is not a storage policy and therefore was not considered relevant for our [energy-storage] proceeding."

The fourth group consists of two state-level tax instruments that have opposing effects on the economics of energy-storage systems for residential PV self-consumption in California. The Sales Tax, which is harmonized and administered by the Board of Equalization (BOE), increases the upfront costs of all storage investments by about eight percent. At the same time, the Property Tax Exclusion (PTE, cf. Fig. 5F), which goes back to two assembly bills that amended California's Revenue and Taxation Code Section 73, exempts buildings with "active solar energy systems" (including storage devices) from increases in property tax that are typically applied when the property value increases, which is usually the case after the installation of solar + storage systems. Finally, on the local policy level, we find that highly location-specific costs for "Permitting, Inspection and Interconnection" may accrue, which depend on the corresponding Authority Having Jurisdiction (AHJ), such as a given municipality (cf. Fig. 5G). It was not possible, therefore, to assign a unanimous policy strategy to this policy instrument, which raises the question of whether it should be conceptualized as part of a local-level policy mix. Complementarities between the Top-Down and Bottom-Up Approaches.

As outlined in the left-hand side of Fig. 6, there is only limited overlap between the two exemplary policy mixes identified though the top down and the bottom-up approaches. Specifically, we find that SGIP

[25] While EPACT was introduced as part of the federal energy policy mix with the direct intent of supporting renewable energy technologies, the EIEA and ARRA frameworks should rather be seen as an immediate response to the global financial crisis, with an indirect intent to foster innovation in the energy domain, e.g. through the foundation of the "Advanced Research Projects Agency – Energy" (ARPA-E) in 2009.

[26] Every three years, the CPUC approves "general rate cases" provided by the state-regulated "load-serving entities" to comply with its mission to provide a "safe, reliable utility service and infrastructure at reasonable rates."

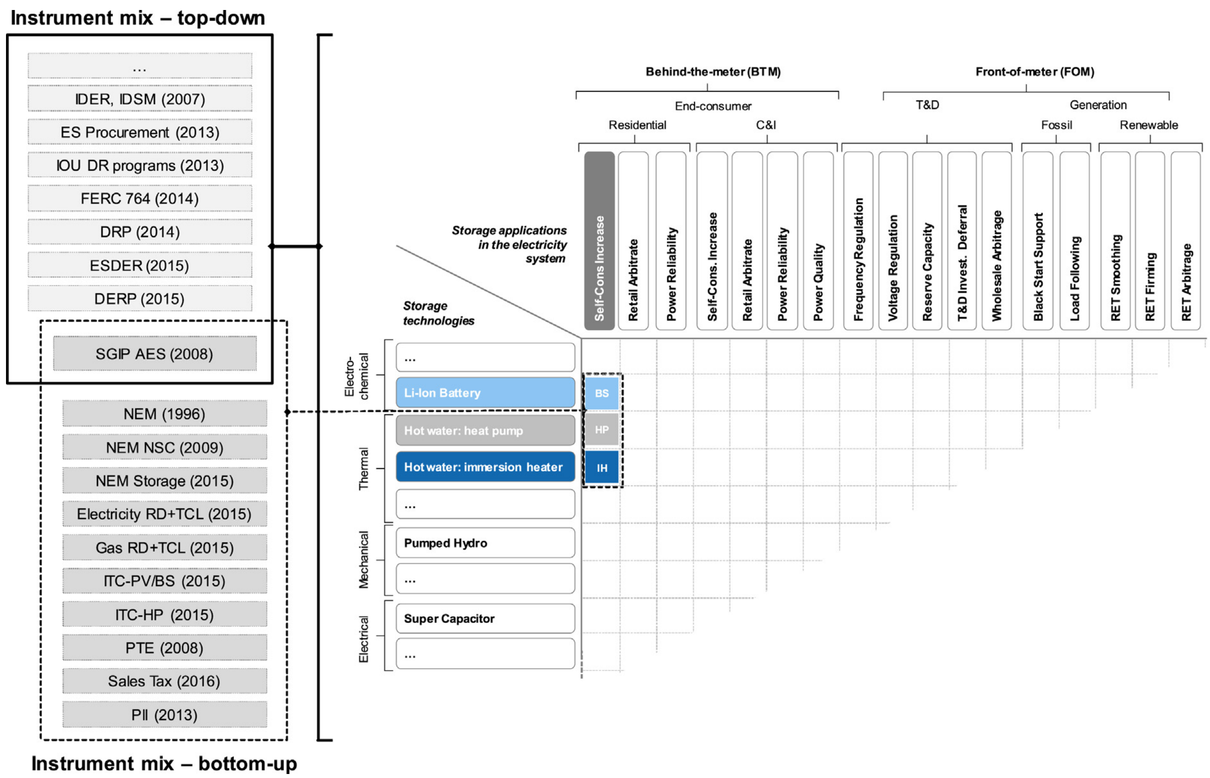

Fig. 6. Comparison of the policy instruments revealed by the exemplary implementation of the top-down and bottom-up approaches; left-hand side: Venn diagram of instrument mixes; right-hand side: stylized overview of the technologies and use cases representing the domain of energy storage'.

Table 2
A guideline for delineating policy mixes.

Category	Top-down	Bottom-up	Combined approach
Define policy mix based on…	■ An overarching strategic intent	■ An impact domain affected by the policy mix	■ A combination of intended and actual effects
Key stakeholders	■ Representatives of entities shaping the policy mix	■ Representatives of entities shaping the impact domain	■ Representatives of entities shaping the policy mix or the impact domain
Advantages	■ Provides overview of complex policy space and its governance structure, potentially based on existing policy inventories ■ Reveals vertical and horizontal coordination challenges *within* a given policy mix	■ Assesses intended and unintended policy effects on a narrow impact domain ■ Reveals vertical and horizontal coordination challenges *across* policy fields	■ Combines the strengths of the top-down and bottom-up approaches ■ Reveals coordination challenges *within and across* policy mixes
Disadvantages	■ Difficult to apply in the initial phase of a policy mix, when domain descriptors are still emerging ■ Prone to a "green field"[a] assumption, i.e. focusing on a niche while neglecting the regime	■ Focuses on idiosyncratic impact domain definition; prone to tunnel vision, reflecting the view of a narrow set of stakeholders ■ Choice of impact metric affects the scope of identified policies[b]	■ Leveraging complementarities between approaches requires sophisticated research design ■ Analytical effort potentially twice as great as for either of the other approaches in isolation

[a] Ignoring the aspect of policy layering and path-dependence, i.e. overlooking the impact of policy instruments that affect the focal impact domain but are not (officially) embraced by the focal strategic intent.

[b] For example, financial instruments have a direct impact on the economics of investments in clean technologies, while regulatory and informatory instruments exert an indirect impact.

is the only element contained in both policy mixes—i.e. it is the only instrument in California's energy-storage policy mix that has an immediate[27] effect on the economics of the three focal energy-storage systems for residential solar PV self-consumption. While this outcome is a direct consequence of their specific implementation, and hence not generalizable,[28] the question arises of whether policy-mix researchers can or should combine both approaches to leverage complementarities between them. To answer this question, it is necessary to take a look at the focal impact domain under investigation.

As illustrated in the right-hand side of Fig. 6, the domain of energy storage comprises numerous different technologies that can be applied in various different use cases across the electricity system. Hence, even when simplifying its multi-goal, multi-level, multi-instrument, and multi-entity nature (e.g. by concentrating on a single policy level), rendering an extensive overview of the policy mix that aims at fostering technological innovation in this domain remains an intricate task. In particular, it involves trading off comprehensiveness against comprehensibility. As shown in Section 4.1, the top-down approach may provide researchers and practitioners with a tool to systematically gain an accessible overview of the relevant policy mix elements and the entities governing it, even in case of complex policy spaces geared towards socio-technical transitions.

However, even with unlimited resources at their disposal, policy mix researchers may find it practically impossible to take into account all the relevant side effects—i.e. second-order or unintended effects—of policy instruments across policy fields when applying the top-down approach. Such a goal can only be accomplished if the spectrum of policy effects to be considered can be significantly narrowed. One way to do so is to adopt the bottom-up approach, which explicitly builds on a narrow definition of a focal impact domain affected by policy (cf. the dotted rectangle on the right-hand side of Fig. 6). The previous section has shown that the bottom-up approach may be used to monitor how policy instruments across policy fields and levels affect the economics of three energy-storage technologies in a particular niche market. This could provide the basis for deriving implications for private homeowners, the associated firms active in California, or representatives of the focal governing entities. For example, the SGIP vs NEM[29] case shows that the bottom-up approach may be useful to reveal and rule out potential inconsistencies between policy instruments that would not be regarded as part of the same policy mix when applying the top-down approach in a narrow sense, as demonstrated in Sections 3.3 and 4.1. Nonetheless, to render a relatively complete overview of an entire technology domain, such as the domain of energy storage, the bottom-up approach would need to be subsequently applied to a myriad of different nested sub-domains affected by policy. Figuratively speaking, it would be necessary to use all the tiles of the "storage matrix" illustrated on the right-hand side of Fig. 6 as a starting point of individual bottom-up approaches.

Hence, for some research projects studying policy mixes, it may be most useful to apply a combination of the top-down and bottom-up approaches. For example, one could discuss the outcome of the top-down approach (cf. Fig. 3) with practitioners active in California's energy-storage ecosystem, such as utilities, storage developers, financial institutions, or NGOs. This could reveal additional insights into policy effects across policy levels, fields, or entities. However, given that applying one of the approaches in isolation is already "a time-consuming and expensive affair" (Howlett et al., 2006, p. 129), researchers should carefully weigh the additional insights gained against the increased effort expended. Bearing in mind the guidelines provided in Sections 2 and 3, researchers may be better off concentrating on one approach and scrutinizing the identified elements in more detail rather than striving for comprehensiveness.

5. Discussion

5.1. A guideline for delineating policy mixes

As shown in the results section, the choice of the methodological approach used to define and delineate policy mixes has a strong influence on which elements provide the basis of the subsequent policy mix analysis (cf. Fig. 2). On the one hand, this clearly demonstrates that an implicit decision about how to derive a given policy mix could lead to a fundamentally different understanding of the same phenomenon, which may entail significant problems for the emerging literature stream on policy mixes in the context of sustainability transitions. On the other hand, being more explicit about the applied approach should also entail an explanation of why this approach is considered most appropriate for the project at hand, since the decision is far from trivial in light of the variety of different policy mix-related research questions and the individual characteristics of the top-down, bottom-up, and combined approaches. To provide policy mix researchers with a guideline for navigating this question, Table 2 summarizes the main features of each approach that should be carefully weighed against each other.

Since the top-down approach draws heavily on information provided by the entities governing the focal policy mix, it is particularly well suited for analyzing the governing structure behind a specific policy mix and its characteristics in terms of coherence and consistency. Such a detailed analysis of the organizational configuration between and within the associated governing entities may subsequently be used to scrutinize a) where policy elements and competences are located; b) whether and how well the former are coordinated; c) whether coherent processes are in place; and d) which institutions need to be changed when it comes to further developing the focal policy mix. For example, the fact that California relies on the distributed capabilities of its existing institutions (cf. Fig. 4), instead of putting in place a dedicated governing agency coordinating the state's energy-transition policy mixes, may provide the basis for a comparative case study drawing contrasts with a more centralized policy mix. However, the top-down approach may also turn out to be problematic if applied too narrowly. While it builds on the notion that the mix of policy instruments pursues an overarching policy strategy, this does not necessarily mean that all those instruments have emerged in response to this very strategy. As revealed by our analysis of California's energy-storage policy mix, several policy instruments existed before innovation in the energy-storage domain became a dedicated strategic objective. This is in line with previous research stressing the importance of path dependence by stating that emerging policy mixes usually layer on, or blend in with, existing policies. In particular, Kern and Howlett (2009, p. 401) have shown that the Dutch energy transition "was expected to rely partly on existing policy instruments (e.g. R&D policy, ETS) and partly upon the development of new ones, with the ambition to create a consistent instrument mix." Policy mix researchers should be aware of this aspect, especially when analyzing the nascent phase of a policy mix, which is fraught with ambiguity in terms of assigning policy instruments to one or more strategies and their respective policy mixes.

Since the bottom-up approach draws on information provided by the stakeholders shaping the focal impact domain and derives the scope of the policy mix inductively, it may include a broad spectrum of policy entities and governance levels. Thereby, it might reveal inconsistencies between more or less unrelated policy domains that could be overlooked when applying the top-down approach in a narrow sense—i.e.

[27] Cf. our statement regarding "indirect policy effects" in Section 3.4.

[28] However, it can be assumed that many empirical settings will be characterized by an m-n relationship between policy mixes and the domains they affect. In other words, a given element of a policy mix may affect multiple impact domains, and a given impact domain may be affected by several different policy mixes.

[29] The NEM scheme is not intended to affect the energy-storage domain—and was therefore not considered a part of the top-down energy-storage policy mix as stated above. At the same time, the scheme strongly affects the economics of distributed energy-storage systems by implicitly offering the electricity grid as a free-of-charge storage alternative—and is therefore included in the bottom-up energy-storage policy mix.

excluding all policy mix elements that do not fall under the focal strategic intent. Moreover, interviews with these stakeholders seem particularly well suited to assessing the aspect of credibility—i.e. whether the focal policy mix is perceived as being believable and reliable. The narrow focus on a particular impact domain and metric also allows researchers to elaborate on the identified policy mix elements using quantitative methods. However, as with the top-down approach, policy mix researchers should be aware that the bottom-up approach can also be applied too narrowly. For example, a bias towards a specific actor network or stakeholder group would immediately affect the scope of identified policy elements, and hence also call the validity of the analysis into question. In addition, drawing on impact domain stakeholders may be especially difficult in the formation phase of a technology, when no clear associations of niche players exist that could voice opinions from the emerging industry.

As shown in the literature review section and Table A1, policy mix researchers have already begun to leverage the complementarities between the top-down and bottom-up approaches outlined in Table 2 by applying them in combination, albeit implicitly. However, when it comes to integrating the insights of multiple data sources and actor networks, the academic literature could apply lessons learned from the systematic stakeholder engagement processes launched by government entities. As outlined in Section 4, in order to develop the Energy Storage Roadmap, state agencies consolidated the inputs of 400 interested parties, representing a wide variety of domains affected by the state's policy reform process[30] in the context of its energy transition. We received a similar statement from an interviewee working at the federal level, who stressed that "for devising the complex regulatory changes necessary all interested stakeholders should be part of the debate." At the same time, this illustrates that the effort involved in combining both approaches should not be underestimated. Without a sophisticated research design, it may be necessary to spend twice as much time on data collection and analysis.

5.2. Limitations and further research

Although policy mixes change over time, we concentrated on a single point in time for our exemplary application of the top-down and the bottom-up approaches. Hence, further research could apply the methodology outlined in Section 3 for several time steps, to track the development of policy mixes over time. In addition, since the bottom-up approach builds on a narrow impact domain affected by policy according to a specific metric, it may be used to assess the effect of policy mixes via quantitative methods. Therefore, further research could draw on e.g. techno-economic modeling to estimate and contrast the individual and combined impact of the policy instruments identified through the bottom-up approach. This could provide further insights—e.g. into how policy mixes affect the competition between different technologies—and thereby help uncover potential inconsistencies between the elements of policy mixes, and, ultimately, improve the coordination of policy instruments within and across policy fields. As part of our empirical analysis we found that in some cases there was ambiguity with regards to the assignment of a given instrument to an overarching strategic intent. In other words, depending on the argumentation, a given instrument could be assigned to multiple strategies. Hence, further research should investigate whether policy mixes can actually be conceptualized as mutually exclusive, and, if not, how the aspect of overlapping assignments can be included in the policy mix framework. Finally, further research should expand the analytical framework introduced in Section 3.1 by developing methodological guidelines for elaborating on the processes and characteristics pertaining to policy mixes.

6. Conclusion

Combining best practices of empirical policy mix analyses with recently consolidated conceptual frameworks, this study introduces two systematic methodological procedures to consistently and transparently define and identify the elements of policy mixes in the context of sustainability transitions. While the top-down approach builds on the notion that a policy mix can be delineated according to an overarching strategic intent, the bottom-up approach captures the intended and unintended effects of policy on a narrow impact domain. Studying the case of energy-storage policy in California, we show that each approach has particular advantages and disadvantages, and therefore lends itself to particular policy mix analyses. The top-down approach is particularly well suited to shedding light on internal dynamics and the governance structure behind a focal policy mix with a given strategic intent. By contrast, the bottom-up approach may be preferable when it comes to analyzing the intended and unintended interactions between policy elements across policy levels, entities, and fields. Despite these differences, we suggest framing the two approaches as complements rather than alternatives. Therefore, we discuss whether policy mix researchers may combine both approaches to leverage complementarities between them, highlighting the tradeoff between increased comprehensiveness and additional effort that they face.

Our study should be regarded as a first step towards a consistent guideline for the initial step of every policy mix analysis—namely, operationalizing the core phenomenon. Hence, we hope that our work motivates researchers to make informed decisions when deciding how to define and identify the elements of the focal policy mix. In this regard, we hope that the top-down vs. bottom-up distinction might serve as both a template and an inspiration for future policy mix analyses.

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Appendix A

[30] Further examples of such stakeholder integration initiatives include the Energy Storage and Distributed Energy Resources Stakeholder Initiative (ESDER), or the Public Tool, a publicly available techno-economic model to moderate the discussion about alternative reforms to the state's Net Metering program (AB327).

Table A1
Literature Review.

Reference	Study goal or research question	Description of policy mix and impact domain	Geogr. & temporal scope	Methodology and data sources	Elements identified	Category
Sorrell (2003)	Develop systematic approach to study policy interactions	Interactions between proposed EU emissions trading scheme and member states' climate policies	EU, UK, NL, DE, FR, GR, 2001–2003	"The empirical work for the project was conducted by five project teams. […] The Partner institutes […] selected a minimum of three national climate policy instruments […]"	Strategy: — Instruments: Six broad categories of policy instruments	Group 1
Howlett et al. (2006)	Compare approaches to dentify the elements of policy mixes in four archetypical policy spaces	Inland water resources (Complex policy space) (Pharmaceutical drug pricing, Marine shipping, and Endangered species protection)	Canada, 2002	Method: Explained in detail throughout a taxonomy of eight basic policy instrument components Data: Public accounts, legislation, regulations; other information available in government databases and documents; interviews with government officials	Strategy: — Instruments: Anecdotal; aggregated assessment of the success and failure of delineating the policy mix in the focal space	Group 1
Kern and Howlett (2009)	How do policy legacies affect transition management efforts?	1. The Dutch energy transition project (ETP) 2. The 'existing' energy policy mix in the Netherlands	Netherlands, 2000–2004	Method: "The goals and instruments […] and their changes over time were traced through the use of several different investigative techniques" Data: interviews with four groups of stakeholders; government documents and peer-reviewed research articles	Strategy and instruments: Comprehensive overview of policy mix elements in 2000 (two strategies and eight types of instruments) and 2004 (three strategies and nine types of instruments)	Group 3
Nauwelaers et al. (2009)	Study EU policy mixes on R&D and derive recommendations	Policy mixes for R&D in Europe; relevant policy instruments are all programs, organizations, rules, and regulations with an active involvement of the public sector, that intentionally or unintentionally affect R&D investments	EU 27 + 4 other countries, 2006–2009	Method: Policy Mix Methodological Report (July 2006); "Definition of policy mixes and analytical framework for policy mix reviews and analyses"; Could not be traced back Data: —	Strategy: — Instruments: R&D-specific and non-R&D-specific policies from the finance, human capital, and innovation domains, as well as eight other policy domains (industry, trade, defence…)	Ambiguous
Sovacool (2009)	Study policy impediments to energy efficiency and renewable power	Renewable electricity and energy-efficiency policy	United States	Method: — Data: 181 research interviews; review of the academic literature	Strategy: — Instruments: List of impediments to effective policy interventions; 30 policy mechanisms identified by interviewees	Group 2
Murphy et al. (2012)	Assess Dutch policy mix in terms of its impact on energy savings in private households	"Policy instruments designed to improve the energy performance of existing private dwellings in the Netherlands"	Netherlands, 2010	Method: Inductive exploration of policies Data: Secondary data sources and interviews with stakeholders involved in the lobbying, design, implementation, promotion, and evaluation of instruments	Strategy: — Instruments: Nine instruments clustered into five categories	Group 1
OECD/IEA/ITF/NEA (2015)	Help align policies for a low-carbon economy	The policy and regulatory frameworks hard-wired to fossil fuels; three core climate policies (CO_2 price, energy efficiency, low-carbon technology support)	–	Method: presumably based on de Serres et al. (2010), "A Framework for Assessing Green Growth Policies" Data: —	Strategy: — Instruments: 21 policy instruments clustered into four categories	Ambiguous
Quitzow (2015)	Develop framework to assess policy approaches promoting environmental technologies	India's [policy] strategy for promoting solar energy technologies: the Jawaharlal Nehru National Solar Mission (JNNSM)	India, 2010–2013	Method: — Data: Three field visits; 50 + interviews with government officials, industry experts and other stakeholders; review of secondary data	Strategy: Overarching policy objective (solar cost reduction), sector-level deployment targets Instruments: approx. 10 most relevant demand and supply side measures	Group 1

(continued on next page)

Table A1 (*continued*)

Reference	Study goal or research question	Description of policy mix and impact domain	Geogr. & temporal scope	Methodology and data sources	Elements identified	Category
BMWi (2016)	Provide overview of the most relevant energy sector policies and the relationships between them	"Overview of legislation governing Germany's energy supply system" "Key strategies, acts, directives, and regulations/ordinances"	Germany, EU (last updated March 2016) Data: —	Method: —	EU: Two strategies, 20 regulations/directives, two reports/guidelines; Germany: One strategy, 24 acts, 33 ordinances	Ambiguous
Del Río et al. (2016)	Evaluate pathways of a harmonised European policy framework for supporting renewable electricity up to 2030	–	EU and member states, 2016–2030	Method: — Data: —	Strategy (implicit): Renewable energy diffusion Instruments: ETS (EU), feed-in tariff, feed-in premium, quota with green certificates, tendering (member states)	Ambiguous
Kivimaa and Kern (2016)	Include 'creation' and 'destruction' as two novel elements in the policy mix framework	"We […] define policy mixes as the specific combinations of policy instruments which interact explicitly or implicitly in fostering (low-energy) innovations and disrupting dominant (high-energy) regimes"	Finland, UK, 2013	Method: Policy mapping exercise; instruments were divided into groups based on their target regime: mobility, heating in buildings and electricity Data: four international policy measure databases	Strategy (implicit): energy efficiency Instruments: 70 (UK), 58 (Finland) initially; additional evidence from interviews (+7 in UK, +3 in Finland)	Group 3
Proudlove et al. (2016)	Provide timely, accurate, and unbiased updates on how states are choosing to study, adopt, implement, amend, or discontinue policies associated with distributed solar photovoltaics (PV)	Policy mix for distributed solar PV, with an emphasis on the residential sector	50 US states, Q4/2014-Q4/2017	Method: manually collect and review proposed and enacted legislative, regulatory policy, and rate design changes affecting the value proposition of distributed solar PV during the most recent quarter Data: state utility commission dockets, legislative bills, press data, direct communication with regulators and industry stakeholders	Strategy: — Instruments: Six actions tracked in focal quarterly report (Net Metering; community solar laws; legislative or regulatory-led efforts to study the value of solar; utility-initiated rate requests for charges applicable only to residential customers with solar PV; utility-initiated	Group 2
Reichardt et al. (2016)	How do the German offshore wind TIS and its corresponding policy mix evolve and influence each other?	The policy mix promoting the development and diffusion of offshore wind in Germany	Germany, 1997–2013	Method: event history analysis (track policy mix evolution) and interviews (gain insights on interdependences) Data: policy documents, interviews with experts representing all main stakeholder groups in the TIS	Strategy: Offshore wind long-term target Instruments: Six instruments and their amendments over time (e.g. EEG), categorized into three different types (tech push, demand pull, systemic)	Group 3
Rogge and Reichardt (2016)	Illustrate conceptual framework for studying policy mixes in the context of sustainability transitions	The policy mix for fostering the transition of the German energy system to renewable power generation technologies	Germany, EU, 1999–2013	Method: — Data: strategy presumably based on (BMWi, 2016); instruments presumably based on (IEA, 2012)	Strategy (exemplary): Strategic Energy Technology Plan (EU), Energy Concept (Germany) Instruments: ETS (EU), Renewable Energy Act/Feed-in tariff, KfW renewable energy program (Germany)	Ambiguous
Kergroach et al. (2017)	Present foundations of the "science, technology, innovation policy" (STIP) database developed and maintained by OECD and the European Commission	National-level innovation policy mixes	54 OECD countries; exemplary focus on France and UK, 2009	Method: Policy mapping; manual review of various international repositories of innovation policy initiatives Data: survey responses; OECD country reviews of Innovation Policy, 2015; EU INNOPro TrendChart database; UK NESTA, government and official agencies websites	www.innovationpolicy_platform.org	Group 1

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Table A1 (*continued*)

Reference	Study goal or research question	Description of policy mix and impact domain	Geogr. & temporal scope	Methodology and data sources	Elements identified	Category
Camillo and Furtado (2018) (this issue)	Understand how contextual factors (country and industry) affect policy and instrument mixes	National wind energy policy mixes	Leader (DK, DE, US) and latecomers (ES, IN, CN), 1973–2014	Method: Policy mapping exercise Data: combination of secondary data sources	Strategy: Separate policy mixes for three "intervention domains" (technological, industrial, and market creation policy) with individual goal Instruments: generic set	Group 1
Huang (2018) (this issue)	Study co-development between multi-level policy mixes and resources mobilisation	Policy mix for solar water heater technology	Shandong province, China, 2004–2016	Method: Following Reichardt et al., 2016: event history analysis combined with expert interviews Data: 255 policy documents related to SWH retrieved from government websites	Strategy: nine elements Instruments: 16 items identified on four policy levels and tracked over time	Group 3
Schmidt and Sewerin (2018) (this issue)	How does the technology specificity of policy mixes affect the diffusion of three particular renewable energy technologies?	Policies affecting bioenergy, wind, solar PV	AU, CA, CH, DE, ES, IR, NZ, UK, 1998–2013	Method: manual collection, review and coding of policy documents Data: several international databases (e.g. IEA Policies and Measures Database), national government reports and websites	Strategy: inductively derived from instruments (e.g. when included in a reform package) Instruments: 562 policy instruments in total	Group 1
Trencher et al. (2018) (this issue)	Assess different types of complementarities between policy instruments	City-level policies seeking to advance (private) building energy efficiency and retrofitting	Four city governments	Method: manual review of policy documents and interviews Data: policy reports, official government websites, academic literature; semi-structured interviews	Strategy: city-level guiding visions Instruments: numerous state-level policies and programs	Group 3

Table A2
Overview of analyzed archival documents.

Category	Major Data Sources	# Documents
Documents on policy strategies *e.g. Executive Orders, Assembly Bills, Senate Bills*	Websites of executive and legislative branch on state (California) and federal level (USA)	93
Documents on policy instruments *e.g. Regulatory Proceedings and Decisions, Program Manuals, AEE database entries*	Websites of governing agencies (especially CEC, CPUC, CAISO, CARB)	123
Ancillary documents *e.g. background literature on California's energy transition, external expert studies, press articles, technical sheets, brochures of energy storage vendors, webinars, conference presentations*	EIA, GTM, Bloomberg, Strategen, Lazard, IERP, RAP, RMI, DRA, NREL, Goldman, Citi, CESA, ESA, HIS, ABB, PV Mag, P3, ISEA	176
	Sum	**392**

Table A3
Overview of interviewee sample.

Stakeholder category	Person	Description
I) Government official/regulator/advisor	A	CPUC, Commissioner
	B	CPUC, Commissioner
	C	CPUC, Staff member
	D	FERC, Department Head
	E	CEC, Department Head
	F	NARUC, Board Member
	G	Minnesota PUC, Commissioner
	H	PSC Washington DC, Department Head
II) Energy-storage industry/association	A	Storage System Developer 1, Head of Energy Policy
	B	Storage System Developer 2, Head of Energy Policy
	C	Storage System Developer 3, Head of Technology
	D	Storage System Developer 4, Head of Business Development
	E	Storage System Developer 4, Head of Sales
	F	Electric Utility 1, Head of Customer Services
	G	Electric Utility 1, Head of Innovation Department
	H	Industry Association 1, Head of Energy Policy
	I	Industry Association 2, Head of Energy Policy
III) Academia/research institutions	A	Private University, School 1, Senior Researcher
	B	Private University, School 2, Senior Researcher
	C	Private University, School 2, Senior Researcher
	D	Private University, School 3, Senior Researcher
	E	Private University, School 4, Senior Researcher
	F	Public Policy Think Tank, Senior Researcher
	G	Private Research Institute, Senior Researcher
Total	**24**	

Table A4
Details of the top-down approach: California's energy-storage policy mix.

Policy Strategy	Type	Brief description of mechanism	Gov. entity/ID	Since
Emission reduction				
EAP	Framework/principal plan	Energy Action Plan (EAP) suggests "loading order" of investment: 1. Energy efficiency and demand response, 2. Renewable and distributed generation, 3. Clean fossil-fueled sources and infrastructure improvements	CEC	2003
SB32, AB32	Reduction target	"Global warming solutions act"; stabilize greenhouse gas (GHG) emissions by 2020, reduce GHG by 80% by 2050	Senate	2016 (2006)
SB350	Reduction target	"Clean energy and pollution reduction act"; focus energy procurement decisions on reducing GHG emissions by 40% by 2030; efforts to achieve > 50% renewable energy, 2× energy efficiency, and gradually electrify transportation	Senate	2015
B-30-15	Reduction target	Reduce GHG emissions by 40% by 2030 compared to 1990 levels	Executive Order Brown	2015
SB185	Divestment	State's largest pension funds divest from coal companies	Senate	2015
Technological innovation—renewables				
SB1078	Renewable Portfolio Standard (RPS)	Mandates state-regulated electricity sellers to purchase 1% of retail sales per year from eligible renewable sources until 20% of sales is reached by 2017	Senate	2002
SB107	RPS Target	Mandates state-regulated retail electricity sellers to purchase 20% of electricity from renewables by 2010	Senate	2006
SB X1-2 (EO S-14-08)	RPS Target	New RPS applies to all electricity retailers in the state; RPS goals of 20% by 2013, 25% by 2016, 33% by 2020	Senate, EO Schwarzenegger	2008, 2011
AB327	Directive	Mandates state-regulated utilities to hand in distributed resource plans (DRPs) by mid-2015; "[…] essentially blueprints for how [utilities] merge rooftop solar, behind-the-meter energy storage, plug-in electric vehicles and other distributed energy resources (DERs) into their […] operations and […]investment regimes" (GTM, 2015)	Assembly	2013
SB350	RPS Target	"Clean energy and pollution reduction act"; increases RPS to 50% by 2030	Senate	2015
Technological innovation—energy storage				
AB2267	Incentive Program	Increases SGIP incentive by 20% if eligible installation comes from a California supplier	Assembly	2008
AB2514	Directive	Directs the CPUC to determine appropriate targets for state regulated utilities to procure viable and cost-effective energy storage systems (outcome: 1,325MW)	Legislature	2010
AB2868	Procurement Target	Increase AB2514 goals by 500MW	Assembly	2016
AB33	Procurement Target	Directs the CPUC and the CEC to evaluate and analyze the potential costs and benefits for all types of long-duration bulk energy-storage resources to help integrate renewable generation into the electrical grid	Assembly	2016
AB1637	Incentive Program	Near-doubles the annual budget of the self-generation incentive program (SGIP, cf. AB970 (2000), SB861 (2014)) from \$83 million to \$160 million	Assembly, Senate	2016

Policy Instruments	Type	Brief description of mechanism	Gov. entity/ID	Since
CPUC				
IDER, IDSM	Directive	Mandates IOUs to integrate customer demand-side programs (e.g. energy efficiency, advanced metering) in a coherent and efficient manner	CPUC, D.07-10-032, R.14-10-003	2007
SGIP AES	Rebate Program	The Self-Generation Incentive Program (SGIP) provides upfront grants (\$81 million annually 2010–2014; extended until January 2021) for the installation of technologies that meet the electric energy needs of a facility; includes "advanced energy storage" (AES) since D.08-11-044 from 2008; includes standalone AES since D.11-09-015 from 2011	CPUC D.01-03-073 (AB970, SB861, SB412, AB1478, AB1637)	2008
Rule 21 Reforms	Grid or Market Access (Distribution/ Retail)	Improve distribution-level interconnection rules and regulations (Electric Tariff Rule 21) for certain classes of electric generators and (new) electric storage resources	CPUC, R.11-09-011	2011
ES Procurement − IOU	Competitive Procurement	Mandates investor-owned utilities (IOU, state regulated) to procure 1325 MW (increased to 1825 MW in 2016) of viable and cost-effective energy storage systems; targets in T&D can also be reached via customer-sited projects	CPUC, R.10-12-007, R.15-03-11, D.16-01-032 (AB2514)	2013
AES RFOs	Competitive Procurement	Request for offers (RFOs) from IOUs to procure advanced energy storage (AES) systems provided by third parties; allows energy storage aggregators to bid into demand-response procurement	CPUC, R.13-09.011	2013

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Table A4 (*continued*)

Policy Instruments	Type	Brief description of mechanism	Gov. entity/ID	Since
DRAM pilot	Competitive Procurement	Third-party demand-response provider bids into CAISO energy (day-ahead + real-time) or ancillary service markets and receives capacity payment	CPUC, CAISO, R.13-09.011	2013
IOU DR programs	Incentive Program	IOUs shall incentivize customers to reduce energy use in homes and businesses to meet grid needs during demand-response events	CPUC, CAISO, R.13-09-011, Rules 24/32	2013
DRP (ICA, LNBA)	Directive	Mandates IOUs to disclose biannually how they include distributed resources (and, within those, distributed energy storage) in their planning and operations	CPUC, R.14-08-013	2014
IRP, LTPP	System planning	Integrated resource and long-term procurement plan	CPUC, R.16-02-007	2015
CAISO				
FERC 719,890	Market Access	Nondiscrimination of "new resources" (e.g. energy storage) for ancillary services	CAISO (FERC 719, 890)	2008
PDR	Market Access	Wholesale demand-response product; Economically triggered "proxy demand resources" (PDR) (such as energy storage) may participate in CAISO markets (energy, non-spinning reserves)	CAISO Docket ER10-765-000 (FERC 719)	2010
NGR	Market Access	Non-generator resources (NGR) (such as energy storage) are allowed to participate in the CAISO market	CAISO (FERC)	2011
FERC755	Pay-for-performance	Increases remuneration for "fast"-responding sources (such as batteries) that bid into frequency reg. markets	CAISO (FERC)	2011
FERC784	Pay-for-performance	Increases remuneration for "fast"-responding sources (such as batteries) that bid into ancillary service markets	CAISO (FERC)	2013
FERC792	Directive	Revises FERC's Small Generator Interconnection Procedures and Agreement to include storage devices	CAISO (FERC)	2013
RDRR	Market Access	Introduces wholesale product reliability demand response resources (RDRR); allows storage to respond to a security of supply event for the delivery of "reliability energy"	CAISO (FERC), CPUC	2014
FERC 764	Market Design (Wholesale)	Introduction of intra-hour transmission scheduling to reduce barriers to integrating variable-energy resources (e.g. storage) and address known market inefficiencies	CAISO (FERC)	2014
WDAT	Grid or Market Access (Transmission/ Wholesale)	Introduces distinction between energy consumption and intermediate storage, the latter being treated as a generation device	CAISO (FERC)	2014
ESISI	Information	Energy storage interconnection stakeholder initiative (ESISI); assessment of whether changes to existing ISO rules are needed to accommodate storage	CAISO (FERC)	2014
ESDER	Information	Energy storage and distributed energy resources (ESDER) stakeholder initiative; increases ability of transmission and distribution resources to participate in wholesale market	CAISO (FERC)	2015
DERP	Market Access	Creates distributed energy resource providers (DERPs) as a new class of grid market players; and allows them to aggregate DERs (such as distributed storage) and participate in CAISO energy or ancillary service markets as "non-generating resources" (NGR)	CAISO (FERC)	2015
CEC				
PIER	R&D support	The Public Interest Energy Research (PIER) program received ~$86.5 million annually (electricity and gas surcharges) to help improve energy-efficiency technologies and strategies (e.g. energy-storage R&DD)	CEC, AB1890	1996–2013
Bi-annual IEPR	R&D support	Every two years, the CEC must file an "Integrated Energy Policy Report" (IEPR) to inform the Governor and Legislature about recent energy policy advances in CA	CEC, D#02-IEP-1ff, SB1389	2003
EISG ESI	R&D support	The Energy Innovations Small Grant (EISG) Program ($2.6 million annual budget) provides financial support to conduct research that establishes the feasibility of innovative energy concepts, such as Energy Systems Integration (ESI) via energy storage	CEC	2007
ES Procurement − POU	Information	Mandates publicly owned utilities (POUs) to develop procurement goals and report targets, progress reports, and policies adopted to the Energy Commission	CEC, AB2514	2013
Inter-agency				
EPIC (SHINES, AES)	R&D support	Electric Program Investment Charge (EPIC); the most comprehensive statewide approach to creating new energy solutions; grant funding for RD&D in e.g. energy storage; ~$10 million for Sustainable and Holistic Integration of Energy Storage and Solar PV (SHINES); $12 million for Developing Advanced Energy Storage Technology (AES)	CPUC, CEC, PON-14-308, DE-FOA-0001108; PON-13-302	2013
ES Roadmap	Information	The report *Advancing and maximizing the value of energy storage technology: a California roadmap* was developed with more than 400 stakeholders and clarifies and prioritizes specific or shared deliverables by each of the three state agencies CPUC, CEC, CAISO in order to "maximize the value of energy storage technology"	CAISO, CEC, CPUC	2014
RA Program	System planning	The resource-adequacy (RA) program provides resources to CAISO to ensure the safe and reliable operation of the grid in real time; latest rulemaking includes establishment of annual local and flexible procurement obligations	CAISO, CPUC, R.14-10-010	2014

Table A5
Characteristics of the three energy-storage technologies used as the basis for the bottom-up perspective.

		Policy goals				
		GHG emission reduction[1]	Renewable integration[1]			Innovation potential[2]
Case	Battery storage systems (BSS)	31%	59%	0%	-15%	High
	Air-sourced heat pump (HP)	48%	35%	0%	7%	Medium
	Immersion heater (IH)	29%	72%	16%	-4%	Low

[1]Indicators derived from a techno-economic model developed by one of the authors (Ossenbrink, 2017a, 2017b). GHG emission reduction compared to a stand-alone residential solar PV system. Renewable integration values shown are: the relative increase in the self-consumption rate (left); the relative decrease in annual maximum PV system power output fed into the grid (middle); and the relative decrease in the annual maximum of the PV system output gradient (right).
[2]Estimate represents inverse of technological maturity. Assessment based on Nykvist and Nilsson (2015) for BSS; Kiss et al. (2012) for HP; and Fuhrs (2015), as well as desk research, for IH.

Table A6
Details of the bottom-up approach: the policy mix affecting the economics of energy storage for residential PV self-consumption in California.

Policy Instruments	Type	Brief description of mechanism	Gov. entity/ID	Since
Federal				
ITC-PV/BSS	Tax Incentive Program	The Investment Tax Credit (ITC), officially known as the "Residential Renewable Energy Tax Credit, is a key federal policy mechanism to support the deployment of solar energy in the United States; taxpayers may claim 30% of the investment into a 'solar dwelling unit' as expenditure on their tax statement (tapered until 2023); potentially includes tax credit for battery storage	U.S. Internal Revenue Service (IRS) Code 25D; American Recovery and Reinvestment Act (ARRA) 2009	2015 (2006)
ITC-HP	Tax Incentive Program	Under the Residential Energy Efficiency Tax Credit (ITC-HP) a taxpayer may claim $300 of the investment into an "Electric heat pump water heater with an energy factor of at least 2.0" as expenditure on their tax statement	U.S. IRS Code 25C; ARRA 2009	2015 (2011)
State				
Group 1				
Electricity RD	Rate design	The CPUC approves the amount that each electric utility can collect from its customers. This is a utility's "revenue requirement" and is based on the cost of operating, maintaining, and financing the infrastructure used to run the utility; and on the cost of its procured fuel and power	CPUC, PUC sections 451, 748; R.12-06-013, electric utilities	2015 (1911)
Gas RD	Rate design	The California Public Utilities Commission (CPUC) regulates natural gas utility service for approximately 10.8 million customers	CPUC, PUC section 451, gas utilities	2015 (1911)
Electricity TCL	Consumption Levies	Taxes, charges, and levies (TCL) on electricity consumption; $1.94ct/kWh PUC reimbursement fee, energy resources surcharge, public purpose program charge, new system generation charge, nuclear decommissioning charge, competition transition charge	CPUC, PUC section 748, Board of Equal. (BoE), electric utilities	2015 (1911)
Gas TCL	Consumption Levies	Taxes, charges, and levies (TCL) on gas consumption; $0.37ct/kWh gas surcharge and state regulatory fee	CPUC section 748, BoE, SB695, gas utilities	2015 (1911)
Group 2				
NEM	Directive	Net energy metering (NEM) encourages private investment in renewable energy resources; NEM is a billing arrangement for customers offered by their electric utility; introduced in 1996 it grants prosumers remuneration at retail value for electricity fed into the grid, a level that significantly exceeds standard wholesale PV electricity rates and the value to the purchasing utility; provides transparent interconnection procedures for small customers	CPUC, AB58 (cost & benefit analysis), AB 920 (NSC), AB327 (NEM successor), D.16-01-044 (charges), R.14-07-002	2016 (1996, 2002, 2013, 2015)
NEM NSC	Directive	At the end of a customer's billing period, any balance of surplus electricity is trued-up at the "Net Surplus Compensation" (NSC) rate, based on a 12-month average of the market rate for energy, ~$0.04–$0.05/kWh	CPUC D.11-06-016 (AB920)	2009
NEM ES	Directive	Clarifies that storage facilities may be treated as an addition to renewable generation, and hence receive the same benefits; small-scale storage systems (< 10 kW) are also excluded from the requirement to install additional metering devices or a non-export relay	CPUC, R.12-11-005, D.14-05-033	2015
Group 3				
SGIP AES	Rebate Program	The Self-Generation Incentive Program (SGIP) provides upfront grants ($81 million annually 2010–2014; extended until January 2021) for the installation of technologies that meet the electric energy needs of a facility; includes "advanced energy storage" (AES) since D.08-11-044 from 2008; includes standalone AES since D.11-09-015 from 2011	CPUC D.01-03-073 (AB970, SB861, AB1478, AB1637)	2008
Group 4				
Sales Tax	Tax & Levies	California's sales tax applies to all retail sales of merchandise (tangible personal property) in the state; increases investment cost by 7.5–10%	BoE, Revenue and Taxation Code	2016
PTE	Tax & Levies	Allows a property tax exclusion (PTE) for certain types of newly constructed "active solar energy systems"; qualifying systems are defined as those that "are thermally isolated from living space or any other area where the energy is used, to provide for the collection, storage, or distribution of solar energy"	BoE, CA Revenue and Tax. Code Section 73, Assessor's office, AB1451, ABX1-15	2008 (1999)
Local				
PII	Grid or Market Access (Distribution/Retail)	Permitting, inspection, and Interconnection (PII) fees; for an average U.S. household, these soft-cost items increase total residential system installation costs by about 3.6% according to NREL	Municipality, Authority having Jurisdiction (AHJ)	2013

(*continued on next page*)

Table A6 (*continued*)

Policy Strategies	Type	Brief description of mechanism	Gov. entity/ID	Since
Behind ITC				
EPACT	Framework/principal plan	Energy Policy Act; provides financial support via investment and production tax credits as well as loan guarantees for eligible energy production technologies; the Energy Policy Act (EPACT) of 2005 required state utility regulators (outside of California) to consider NEM	Passed House and Senate; enacted by President Bush	2005
EIEA	Framework/principal plan	Energy Improvement and Extension Act of 2008 (EIEA); part of the Emergency Economic Stabilization Act of 2008; provides financial support via specific tax credits or incentives to support	Passed House and Senate; enacted by President Bush	2008
ARRA	Fiscal policy response	American Recovery and Reinvestment Act (ARRA); stabilized the US economy in the aftermath of the financial crisis; appropriated $787 billion out of which $90 billion was allocated towards investing e.g. in the Advanced Research Projects Agency-Energy (ARPA-E) program that supported innovations such as storage	Passed House and Senate; enacted by President Obama	2009
Behind rate design				
PUA	Constitutional Amendment	The Public Utilities Act (PUA) expanded the Railroad Commission's regulatory authority; today, the CPUC (renamed in 1946) regulates privately owned electric, natural gas, telephone, water, and sewer utilities	Legislature	1912
Behind NEM				
Deregulation	Directive	Deregulated the state's IOUs to increase competition, and drive down electricity and gas prices. Created incentives for grid-tied PV systems under the CEC's Renewable Energy Program	AB1890 (Electric Utility Industry Restructuring Act), SB656	1996
PUC2827	Directive	Encouraged investment in distributed generation (DG) and develop a self-sustaining market for "emerging" renewable energy technologies in DG applications	PUC section 2827	1996
RESIA	Directive	Reliable Electricity Service Investments Act (RESIA) enacted by Governor Wilson	AB995, SB1194, SB1038	2000
AB327	Directive	Ensured that customer-sited renewable distributed generation continues to grow beyond 5% NEM program limit or past eligibility time frame of July 2017; successor tariff must be based on the costs and benefits of the renewable electrical generation facility	Assembly, Gov. Brown	2013
Behind SGIP				
AB970	Directive	Required the CPUC to initiate load control and distributed generation (DG) activities; technologies include internal combustion engines, photovoltaics, fuel cells, and combined heat and power	Assembly	2000
D.08-11-044	Decision	Determined that Advanced Energy Storage systems coupled with eligible SGIP technologies will receive an incentive of $2/watt of installed capacity	CPUC	2008
SB861	Directive	Extended SGIP funding through 2019 and extended SGIP administration until January 1, 2021; changes the California supplier requirement to "manufactured in CA"	Senate	2014
AB1478	Directive	Clarified that eligible technologies can shift onsite energy use to off-peak times	Assembly	2014
AB1637	Incentive Program	Near-doubles the annual budget of the self-generation incentive program (SGIP, cf. AB970 (2000), SB861 (2014)) from $83 million to $160 million	Assembly, Senate	2016
Behind Taxes				
BoE	Constitutional Amendment	Established in 1879 by constitutional amendment, the Board of Equalization (BoE) ensured that county property tax practices were equal and uniform across CA. Currently, BoE programs (e.g. sales & property tax) account for > 30% of state revenue	Legislature	1879
Behind PII				
AHJ	–	Depends on "Authority Having Jurisdiction" (AHJ), e.g. municipality	–	–

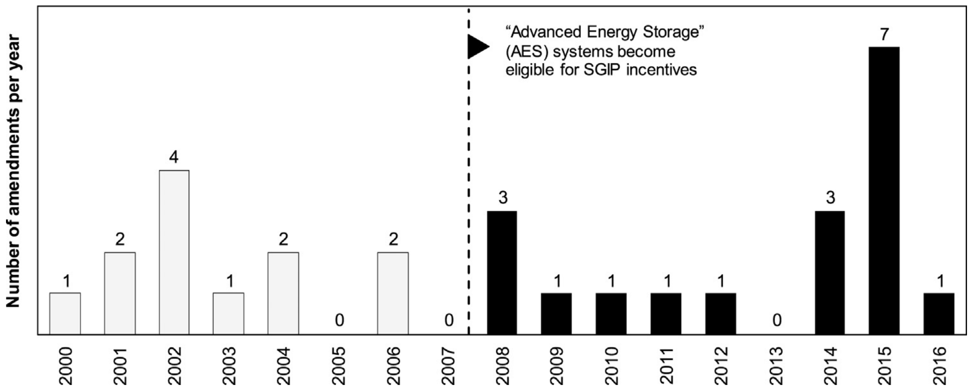

Fig. A1. Number of amendments to California's Self-Generation Incentive Program (SGIP); Authors' own illustration based on data provided in SGIP Handbook 2016 (CSE et al., 2016, p. 81ff).

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